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IMPROVEMENTS OF THE MODEL ATMOSPHERE

R. A. MINZNER

(NASA CONTRACT ~~NO.~~ NAS 5-270)

[7]

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GODDARD SPACE FLIGHT CENTER
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GEOPHYSICS CORP~~ORATION~~ OF AMERICA,
BEDFORD, MASS~~ACHUSETTS~~

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IMPROVEMENTS OF THE MODEL ATMOSPHERE

1. Introduction

The work in model atmospheres performed as a small part of contract NAS5-270 has been directed almost entirely toward the development of a revised United States Standard Atmosphere through cooperation with the committee on extension of the Standard Atmosphere COESA, and several of its Working Groups I, II and IV, on which the writer has served. Consequently, this report will deal with the important contributions made under this contract toward the establishment of the Proposed Revision but will only touch on the conclusions of the work of Task Group IV which work was completed with different funds in support of the missile trail program after the exhaustion of funds on this NASA contract.

The early history of standard atmospheres is discussed elsewhere.(1) The ARDC Model Atmosphere 1956(2) and the nearly identical U. S. Standard Atmosphere(3) (with its tentative and speculative regions) were based on pressure data to 120 km. This model was designed to be compatible with and continuous with the ICAO Standard Atmosphere at 20 km where the latter model ended. This 1956 model represented a significant improvement over the previous Warfield Tentative Standard which had been calculated for altitudes up to 120 km only, and which was not compatible with the ICAO Standard Atmosphere adopted by the U. S. in 1952. Furthermore, the 1956 Model with its extension through a few density points between 120 and 160 km provided a reasonable speculation concerning the nature of the atmosphere up to 200 km, and a much less reliable speculation for altitudes above 200 km.

The launching of the First artificial earth satellite in 1957 permitted the determination of drag acceleration, and hence density, at about 220 km where the density was found to be about 3 times greater than that of the U. S. Standard or 1956 ARDC Model. Subsequent satellites in July, 1958, indicated even greater discrepancies at higher altitudes such that at 300 km, the top of the U. S. Standard, the observed drag accelerations inferred densities 10 times greater than those of the standard.

Using the satellite-derived data available in late 1958 plus the additional rocket-derived data, obtained since 1955 the ARDC Model Atmosphere 1956[4] was modified, and with detailed calculation was published as the ARDC Model Atmosphere 1959[5]. This model was prepared to match the atmospheric conditions as observed near the peak of the sun spot cycle. This model departed from the 1956 model at 53 km altitude, within the tentative region of the U. S. Standard, and hence did not disturb the established standard region below 32 km. Early in 1960 attempts were initiated[6] to replace the tentative and speculative regions of the U. S. Standard Atmosphere with the 1959 Model. One of the steps required to ensure the stability of the lower region of the model was to obtain ICAO adoption of that portion from 20 to 32 km. Due to one significant scientific objection and several minor technical objections, from other member nations the U. S. representative to ICAO withdrew the proposal. COESA, therefore, deemed it desirable to redefine the U. S.

Standard between 20 and 32 km so as to meet the ICAO objections, and to make any high altitude revisions continuous with these low-altitude revisions. A considerable amount of new directly-measured temperature data between 40 and 90 km plus more satellite drag data, the later of which suggested diurnal as well as long term variations of the density above 200 km, resulted in the decision to bypass the direct use of the 1959 ARDC Model and to devise a new U. S. Standard, directly from the data.

The Working Group of COESA at its January, 1961, Meeting[7] at MIT approved the appointment of three subcommittees or task groups, each to make recommendations concerning a specific region of the atmosphere; Task Group I, 20 to 90 km; Task Group II, 90 to 200 km; and Task Group III, 200 to 700 km. In preparation for the January, 1961, meeting of the Working Group of COESA a compliation of available atmospheric data at altitudes below 200 km was made. These data, presented graphically in Section 2, contributed to the selection of the revised value of temperature and altitude of the mesopeak, and between 90 and 200 km served as the basis for the calculation of the revised model as prepared by Task Group I[8].

In comparing the several preliminary models suggested by Task Group III[9] with the Jacchia model[10], a study was made of the Jacchia scale height data. These data, it appeared, are derived from the slope of the density-height curve and consequently are not identical to scale heights derived from the slope of the pressure-height curve. An analysis of this problem was made, and an equation developed which permits the computation of T_M or pressure scale height, as well as dT_M/dZ from tabular density scale height. This study is presented in Section 3.

The Report of Task Group II[11], which was prepared principally under this contract, and which was presented to the Working Group of COESA at its June 26, 1961, Meeting at Woods Hole, Massachusetts,[12] is presented in this report as Appendix A.

Through close coordination between Task Groups I and II, the model presented by these two groups followed continuously and rigorously from the ICAO Standard at 20 km to an altitude of 200 km. Task Group III, however, using a model-development technique of integration downward from the highest altitude to determine the temperature, produced several models, none of which was continuous in density or temperature with the upper end of the model of Task Group II. In addition, the Task Group III Models were not defined in terms of linear segments of molecular scale temperature vs. geometric altitude as requested by the Working Group at its meeting in January, 1961.

The three Task Groups presented their models to the Working Group at the Woods Hole meeting[12]. Each report was accepted with commendation for its scientific content, but with the reservation that some of the technical aspects of the model of Task Group III required clarification, as well as matching to the model of Task Group II at 200 km. Thus, Task Group IV was appointed to develop a continuous and consistent model between 90 and 700 km, while keeping as close as practicable to the models prepared by Task Groups II and III.

Since the contract herein reported, terminated shortly after the above mentioned June meeting, the complete work of Task Group IV is not presented in this report. As of this writing, however, an interim report subject to the approval of the balance of the Task Group has been prepared and is being reported under Air Force contract AF19(628)-231. A few excerpts of this report are presented in Section 4.

2. Atmospheric Data Survey as of January, 1961

A. Value of Mesopeak Temperature

In preparation for the discussion of the proposed revision of the U. S. Standard Atmosphere at the January, 1961, meeting of the Working Group of COESA[7] at MIT, a survey was made of pressure and density data from 40 to 220 km, and of temperature data in the 40 to 60 km region of the mesopeak.

The temperature data were plotted in three different ways: first, in terms of the maximum value of temperature versus time chronologically from 1947 through 1958, the latest date for which the writer had data. This graph was intended to show any long term variation; the second graph depicts the maximum(mesopeak) value of temperature versus day of the year independent of the calendar year, thereby showing any seasonal variation; the third graph examines the maximum value of temperature versus hour of the day independent of season or year. The latter presentation ruled out all of the anomalous sound propagation data and other data for which no specific time of day was available. These three studies are presented in Figures 1, 2, and 3 respectively.

Each of these presentations show a wide range of temperature variation but no consistent, long-term,seasonal,or diurnal variation is evident from a visual examination of these scatter diagrams. A more precise statistical study might show some trends but since the errors associated with any of these measurements is almost certainly of the order of ± 5%,

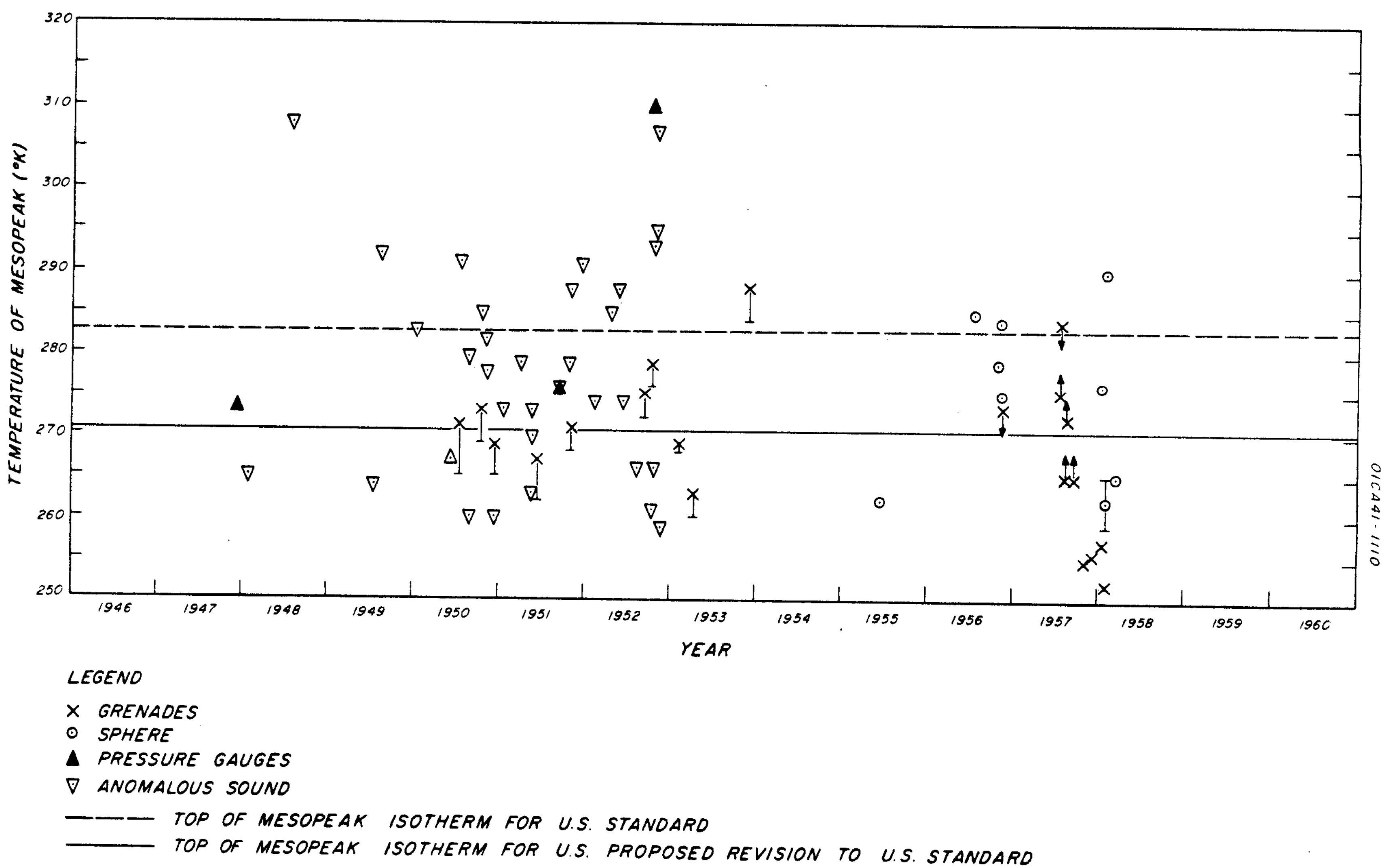
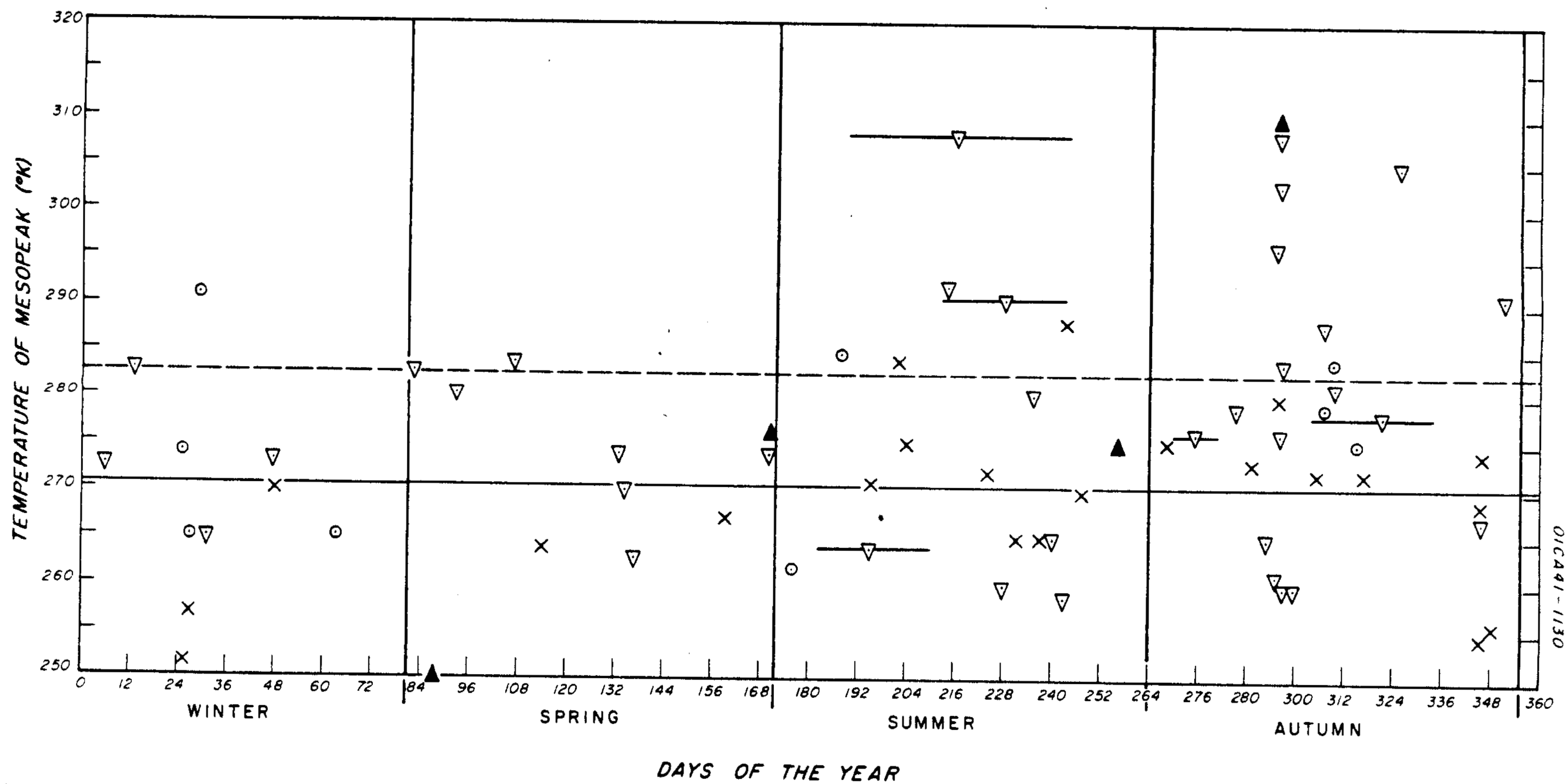


Figure 1. Mesopeak Temperature Versus Chronological Time, 1947 through 1958.



HORIZONTAL LINES ASSOCIATED WITH DATA POINTS INDICATE PERIOD FOR WHICH THE DATA APPLY AS AN AVERAGE

Figure 2. Mesopeak Temperature Versus Day of the Year Independent of Calendar Year.

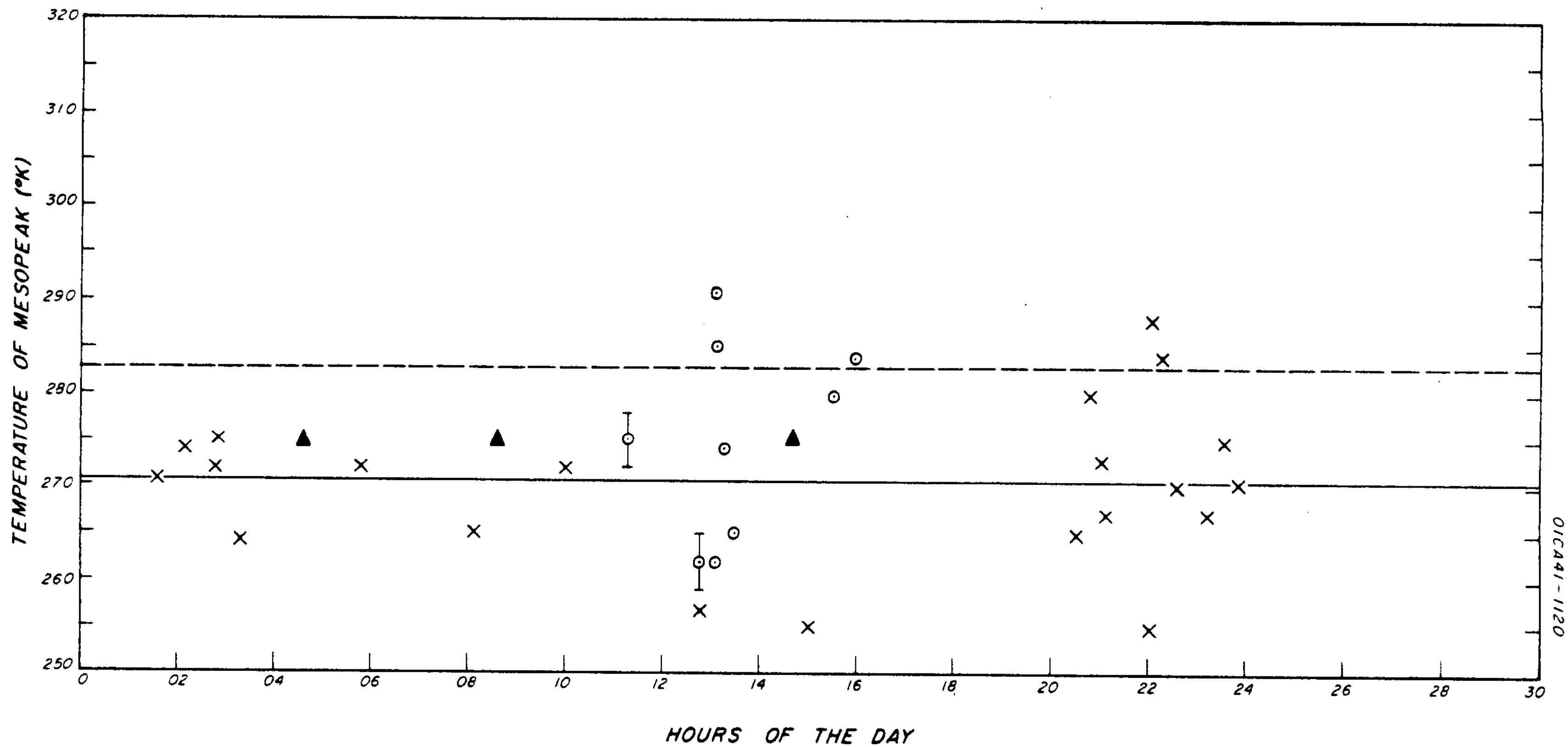


Figure 3. Mesopeak Temperature Versus Hour of the Day Independent of Day of the Year or Calendar Year.

it is questionable whether the additional effort would be worthwhile. The one significant fact which this study shows is that the average value of the mesopeak temperature should be lower than the 282.66°K of the U. S. Standard. When the anomalous sound propagation results are considered, the mean temperature seems to be about 274°K. When the rather unreliable, anomalous-sound-propagation results are omitted, the mean value of mesopeak temperature appears to be nearer 270°K. This study supported the selection[8] of 270.65°K as the temperature of the mesopeak.

A further distinction in the analysis of the data as to where the observations were made, Canal Zone 9°N, White Sands 32°N, Colorado and Wallops Island 39°N, Fort Churchill 59°N, and Alaska 64°N showed no significant variation, although a more carefully made set of observations may well show the existance of some latitude dependence. This latitude distinction made through the use of color distinction in the original graphs is not carried out in this report.

B. Height of Mesopeak

The temperature data used in the above discussion, with the anomalous sound propagation results excluded, were replotted in terms of the altitude of the mesopeak versus time in the same three forms used above, i.e.; (1) chronological time 1947 through 1958; (2) season of the year; and (3) time of day. These graphs are presented in Figures 4,5 and 6 respectively. These data show the mesopeak to occur at altitudes ranging from

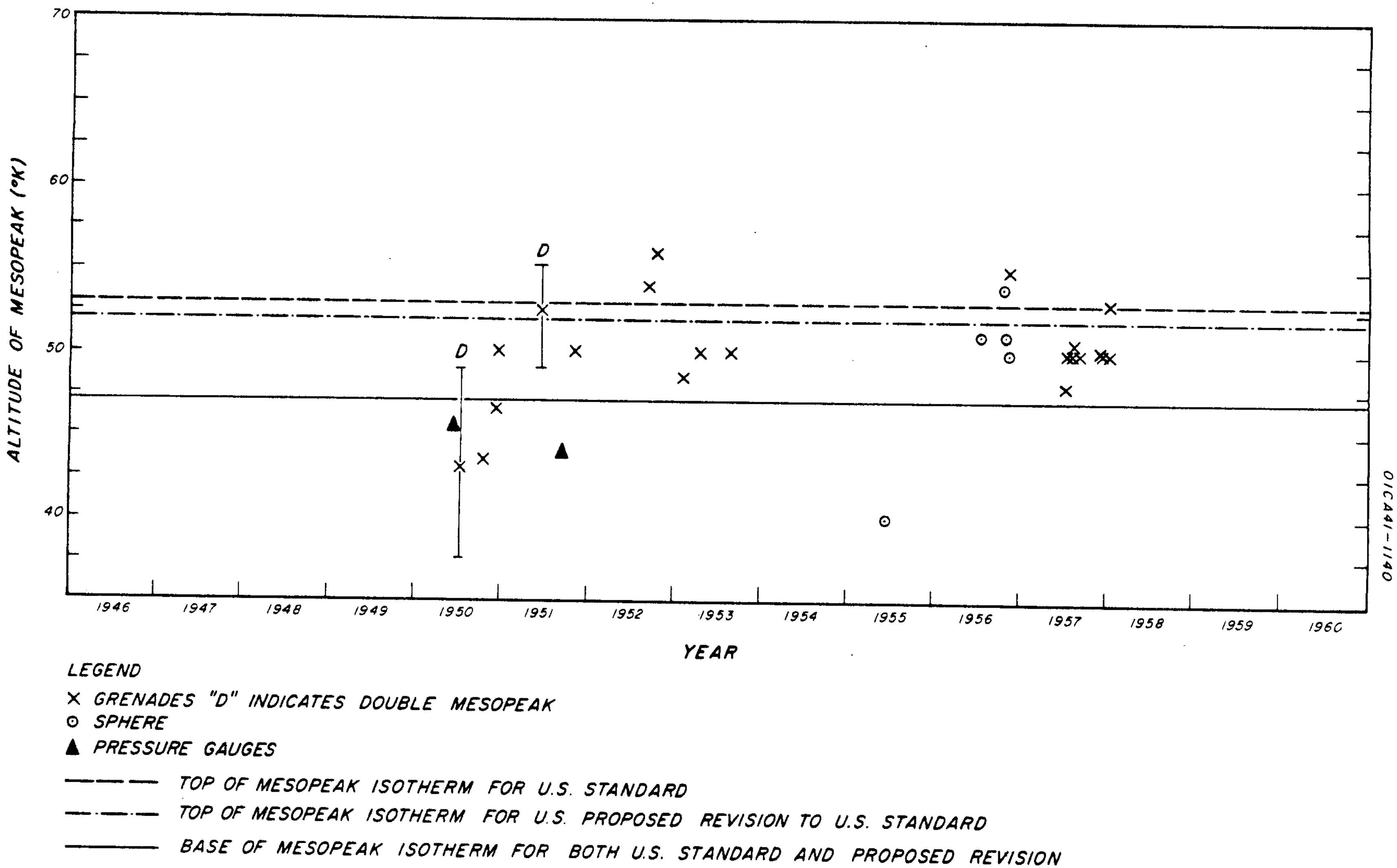


Figure 4. Height of Mesopeak Versus Chronological Time, 1947 through 1958.

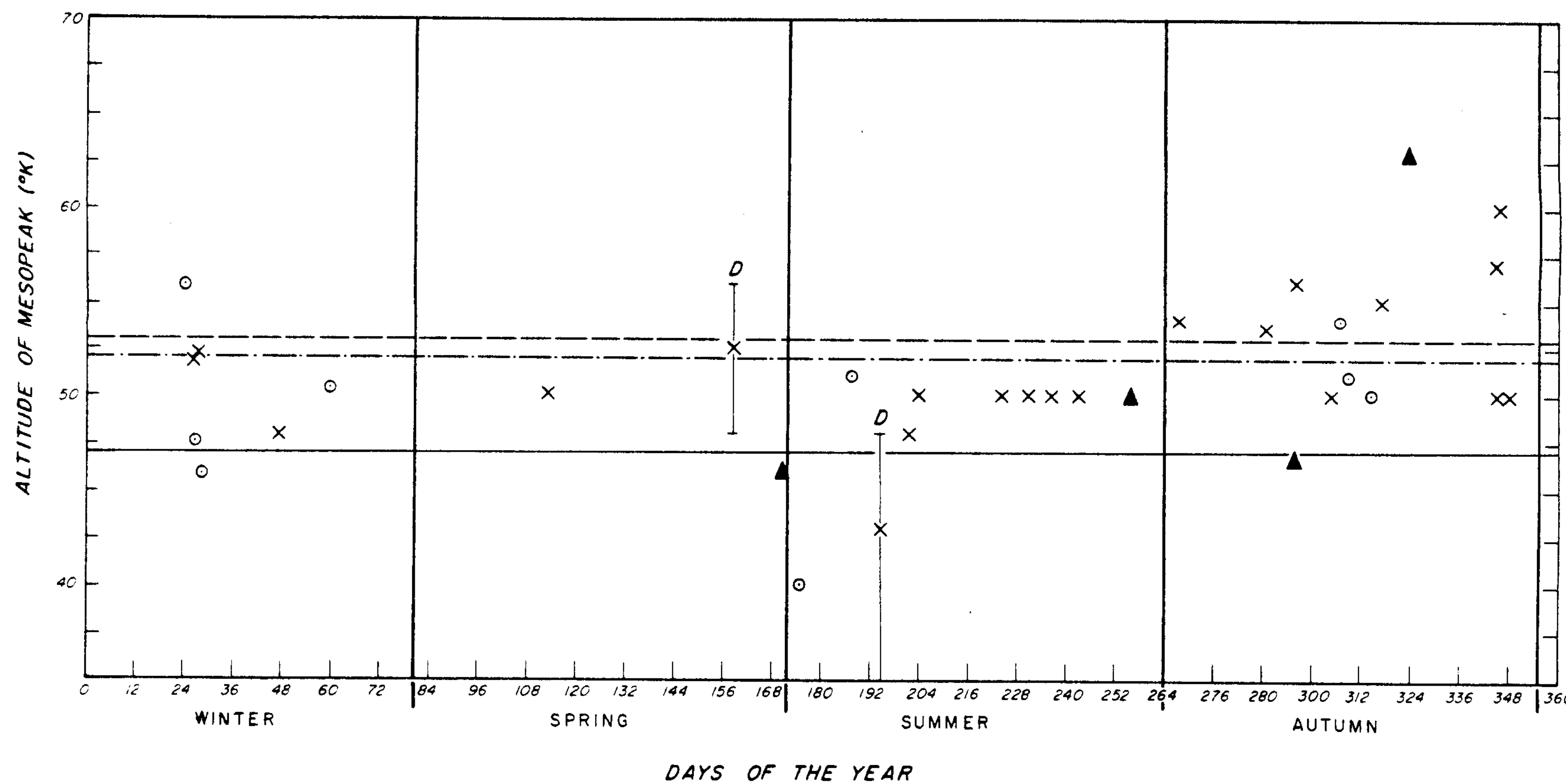


Figure 5. Height of Mesopeak Versus Day of the Year Independent of Calendar Year.

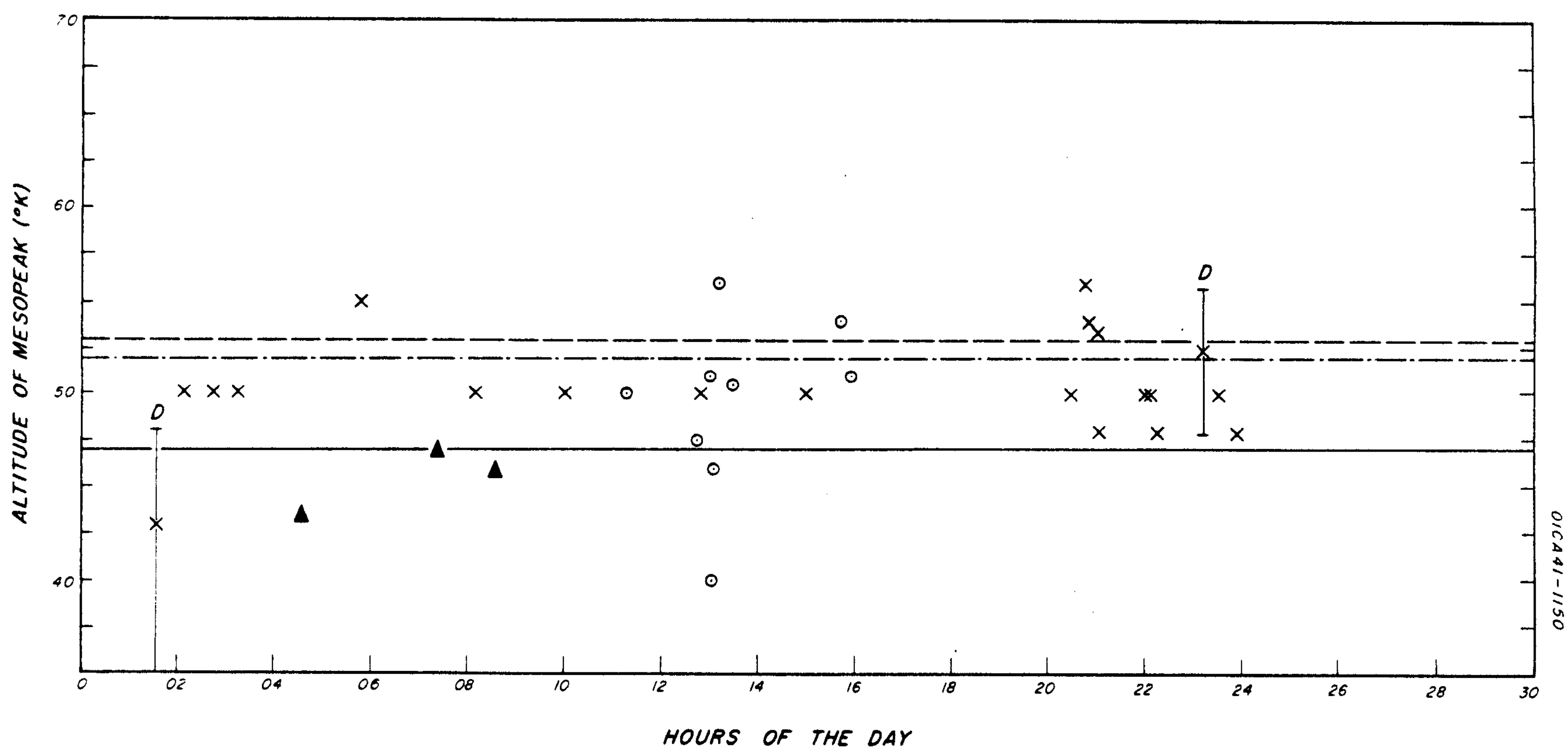


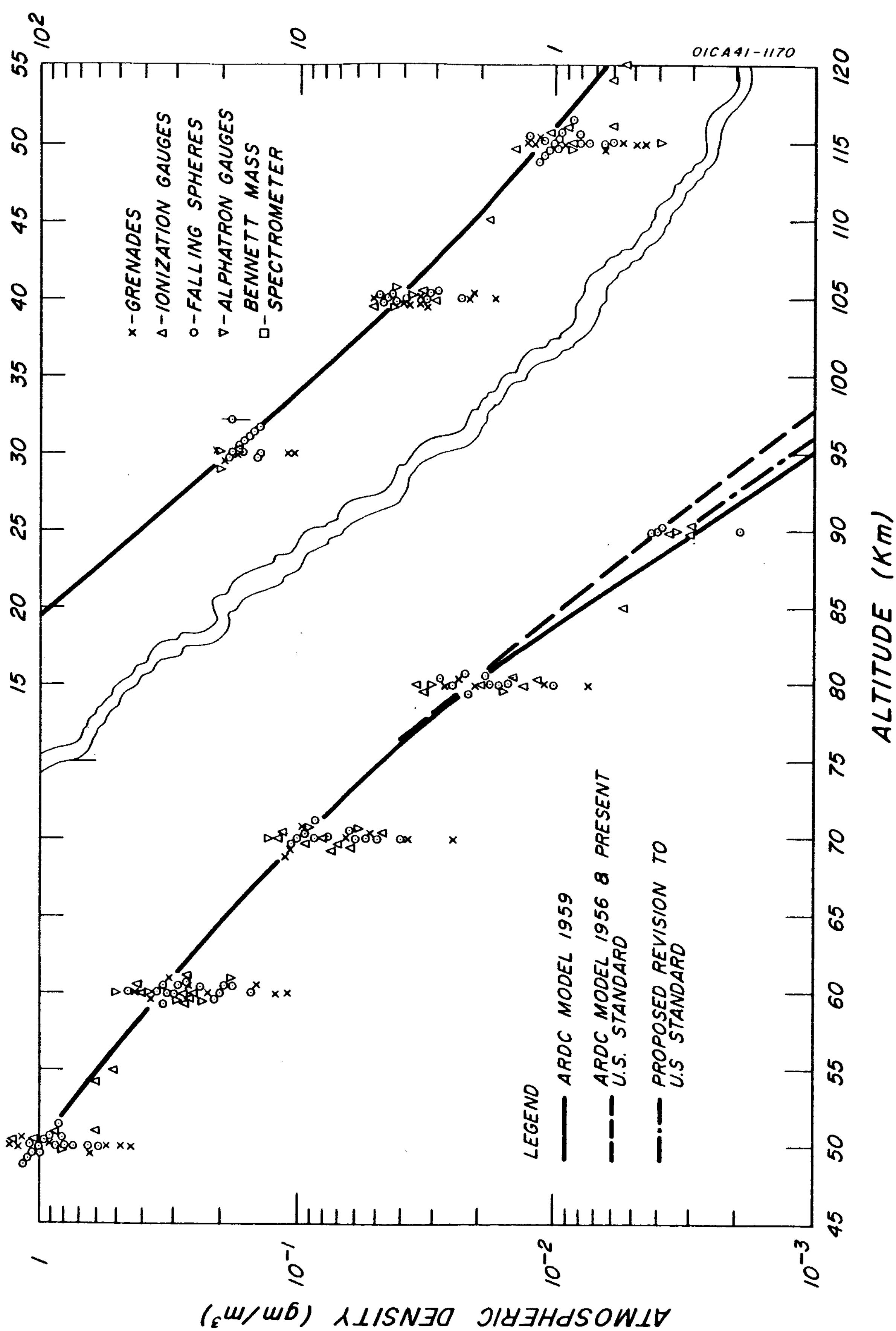
Figure 6. Height of Mesopeak Versus Hour of the Day Independent of Day of the Year or Calendar Year.

35 to 62 km but with the preponderance of points occurring between 45 and 55 km. There appears to be a slight indication that the height of the mesopeak rises in the afternoon or that it is higher in the Autumn and Winter than in the Spring and Summer. These two factors have not been separated and the number of available data points appear to be too small to adequately determine which of these two factors is the dominant one.

A mean value of slightly under 50 km is evident from the graph and the extended region 47 to 52 km, selected for the proposed revision to the U. S. Standard[8], is supported by this study.

C. Density Vs. Altitude Distribution

The altitude distribution of mass density from rocket-borne instrumentation is summarized in Figures 7, 8, and 9, along with curves for the U.S. Standard and the ARDC Model 1959. Data were taken for every 10 km, except at peak altitudes for specific flights where values were plotted for the odd altitudes. Where several data points would have fallen on top of each other, or nearly so, the various points were distributed along a line having a slope similar to that of the average density-altitude curve for that altitude region. These data served primarily in the selection of the model above 90 km by Task Groups II[11] and IV[13].



01CA41-1170
ATMOSPHERIC DENSITY (gm/m³)
ALTITUDE (Km)
x - GRENADES
Δ - IONIZATION GAUGES
o - FALLING SPHERES
∇ - ALPHATRON GAUGES
□ - BENNETT MASS SPECTROMETER
LEGEND
ARDC MODEL 1959
ARDC MODEL 1956 & PRESENT U.S. STANDARD
PROPOSED REVISION TO U.S STANDARD

Figure 7.

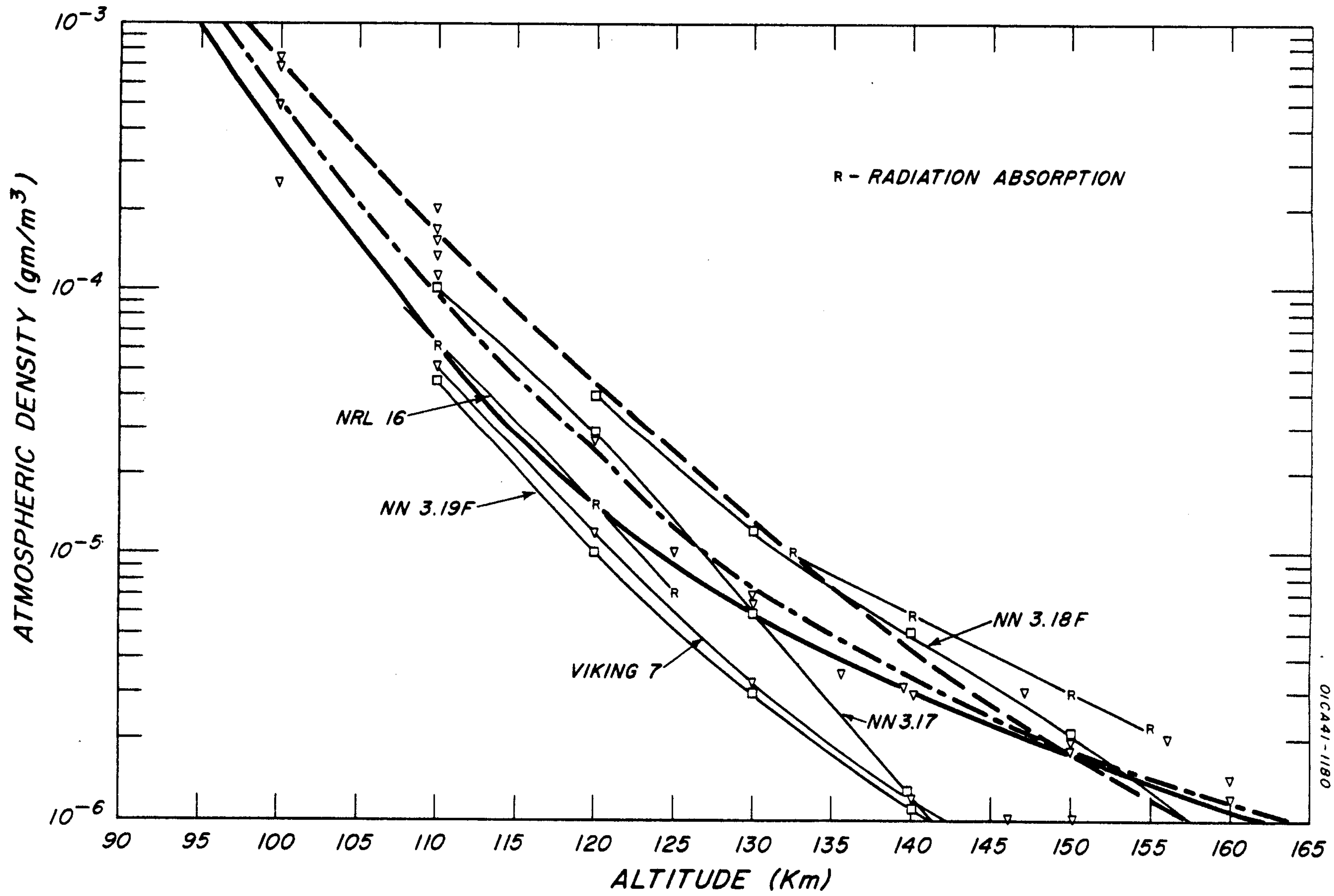
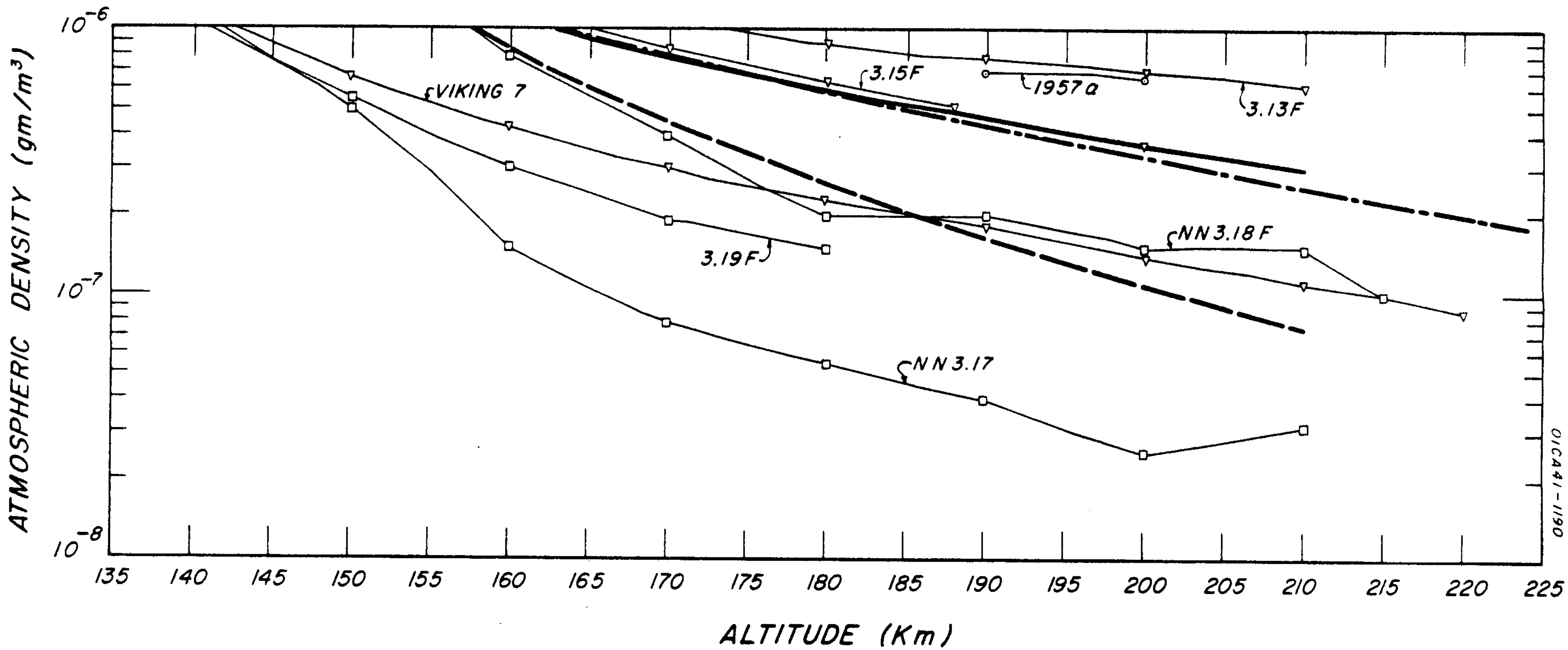

R - RADIATION ABSORPTION
NRL 16
NN 3.19F
VIKING 7
NN 3.17
NN 3.18F
ATMOSPHERIC DENSITY (gm/m³)
10⁻³
10⁻⁴
10⁻⁵
10⁻⁶
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
ALTITUDE (Km)
01CA41-1180

Figure 8.



01CA41-1190
ATMOSPHERIC DENSITY (gm/m³)
10⁻⁶
10⁻⁷
10⁻⁸
ALTITUDE (Km)
135
140
145
150
155
160
165
170
175
180
185
190
195
200
205
210
215
220
225
VIKING 7
3.15F
1957a
3.13F
3.19F
NN 3.18 F
NN 3.17

Figure 9.

3. Pressure Scale Height Derived from Density Scale Height

A. Definition of Several Kinds of Scale Height

In the comparison of atmospheric models and data during the preparation of a Revised U. S. Standard Atmosphere, it became necessary, for proper evaluation, to examine the significance of a new kind of scale height, values of which were published by Jacchia[10]. This scale height is a quantity which he deduced simultaneously with the generation of density data in the process of analyzing satellite drag accelerations by a formula developed by King-Hele, Cook and Walker[14] Although Jacchia makes no specific mention of the exact significance of this scale height, King-Hele[14, 15, 16] indicates it to be defined as the slope of the curve $\ln_\rho$ vs. z where ρ is density and z is altitude. Minzner [17] suggested that an appropriate name might, therefore, be density scale height H_ρ. This definition makes H_ρ different from the Chapman scale height except perhaps for regions where T, the kinetic temperature, and M, the mean molecular weight, or the ratio T/M do not change with altitude, and where there are no sources or sinks of any specific species of molecule. This definition also implicity assumes a variable acceleration of gravity g and removes some uncertainty (with regard to the variation of g)normally associated with the more conventional Chapman scale height H, which usually infers a constant gravity, For this discussion, both pressure scale height H_P and density scale height H_ρ (each defined mathematically below) assume a value of g which varies as the inverse square law.

In order to distinguish precisely between these several scale height concepts, the following definitions are presented:

(1) Scale height H is defined by the relationship:

$$H \equiv \frac{RT}{g_o M} = \frac{RT_M}{g_o M_o} \tag{1}$$

where g_o is the sea-level value of g

M_o is the sea-level value of M and

T_M is defined as $M_o(T/M)$.

This quantity H (having the dimension of length) and occurrring in the reciprocal form in the exponent of the barometric equation, when the variation of gravity is neglected, is the well-known Chapman scale height.

(2) Pressure scale height H_p is defined by the relationship

$$H_p \equiv \frac{RT}{gM} = \frac{RT_M}{gM_o} \tag{2}$$

where g is a variable. Because of the relationship expressed in the differential form of the barometric equation,

$$\frac{d \ln p}{dz} = \frac{-gM}{RT} = \frac{-gM_o}{RT_M} = \frac{-1}{H_p} \tag{3}$$

where p is total pressure of the atmosphere, the negative reciprocal of the pressure scale height is implicity a measure of the slope of the ln p vs. z profile in an atmosphere where the acceleration of gravity g, kinetic temperature T and mean molecular weight M, are all variables, but where these are also the only variables affecting the pressure-altitude profile. The source of variation of M, diffusive separation, dissociation, recombination, etc. is immaterial.

(3) Density Scale height H_ρ, by analogy with Equation (3) is defined by the expression

$$\frac{-1}{H_\rho} = \frac{d \ln \rho}{dz} \quad . \tag{4}$$

and as a result of the analogy will be considered as applicable to the same kind of atmosphere to which H_p applies, i.e., variable g, T and M.

B. Interrelation of Pressure Scale Height and Density Scale Height Through Temperature and Gradient of Temperature

The equation of state relates pressure and density by

$$\rho = pM/RT = pM_o/RT_M, \tag{5}$$

from which one may write

$$\ln \rho = \ln p + \ln M - \ln R - \ln T = \ln p + \ln M_o - \ln R - \ln T_M, \tag{6}$$

and

$$\frac{d \ln \rho}{dz} = \frac{d \ln p}{dz} + \frac{d \ln M}{dz} - \frac{d \ln T}{dz} = \frac{d \ln p}{dz} - \frac{d \ln T_M}{dz} \; . \tag{7}$$

Introducing Equations (3) and (4) into Equation (7) yields

$$\frac{-1}{H_\rho} = \frac{-1}{H_p} + \frac{1}{M}\frac{dM}{dz} - \frac{1}{T}\frac{dT}{dz} = \frac{-1}{H_p} - \frac{1}{T_M}\frac{dT_M}{dz} \tag{8}$$

from which it is apparent that H_p and H_ρ cannot be equal except under the conditions that dT_M/dz is zero, i.e.,

$$\frac{dT_M}{dz} = M_o \frac{d(T/M)}{dz} = \frac{M_o}{M}\frac{dT}{dz} - \frac{T M_o}{M^2}\frac{dM}{dz} = 0. \tag{9}$$

From Equation (9), it is evident that this condition exists when neither T nor M vary individually with altitude, or when the ratio (T/M) does not vary with altitude).

From Equation (8) one may then write the following expressions for H_p and H_ρ, i.e.,

$$H_p = \frac{H_\rho}{1 + \frac{H_\rho}{M}\frac{dM}{dz} - \frac{H_\rho}{T}\frac{dT}{dz}} \cdot = \frac{H_\rho}{1 - \frac{H_\rho}{T_M}\frac{dT_M}{dz}} \tag{10}$$

and

$$H_\rho = \frac{H_p}{1 - \frac{H_p}{M}\frac{dM}{dz} + \frac{H_p}{T}\frac{dT}{dz}} = \frac{H_p}{1 + \frac{H_p}{T_M}\frac{dT_M}{dz}} \tag{11}$$

C. <u>Transformation of Tabular Values of Density Scale Height Vs. Altitude into Tabular Temperature Data</u>

Replacing H_p in the right hand member of Equation (11) by its equivalent RT_M/gM_o leads to

$$H_\rho = \frac{T_M}{\frac{M_o g}{R} + \frac{dT_M}{dz}} \tag{12}$$

from which we have

$$\frac{dT_M}{dz} = \frac{T_M}{H_\rho} - \frac{gM_o}{R} . \tag{13}$$

By differentiating Equation (12) with respect to Z one obtains

$$\frac{dH_\rho}{dz} = \frac{\dfrac{dT_M}{dz}}{\dfrac{gM_o}{R} - \dfrac{dT_M}{dz}} - \frac{T_M\left(\dfrac{M_o}{R}\dfrac{dg}{dz} + \dfrac{d^2T_M}{dz^2}\right)}{\left(\dfrac{gM_o}{R} + \dfrac{dT_M}{dz}\right)^2} \tag{14}$$

Combining Equation (13) and (14) permits the following expressions,

$$T_M = \frac{\dfrac{M_o}{R}\left(gH_\rho + \dfrac{dg}{dz}H_\rho^{\,2}\right) + H_\rho^{\,2}\dfrac{d^2T_M}{dz^2}}{1 - \dfrac{dH_\rho}{dz}} \tag{15}$$

When in the analysis of data, it is permissable to consider the T_M of Z function to consist of short linear segments of constant dT_M/dZ, the term involving d^2T_M/dZ^2 becomes zero and Equation 15 becomes

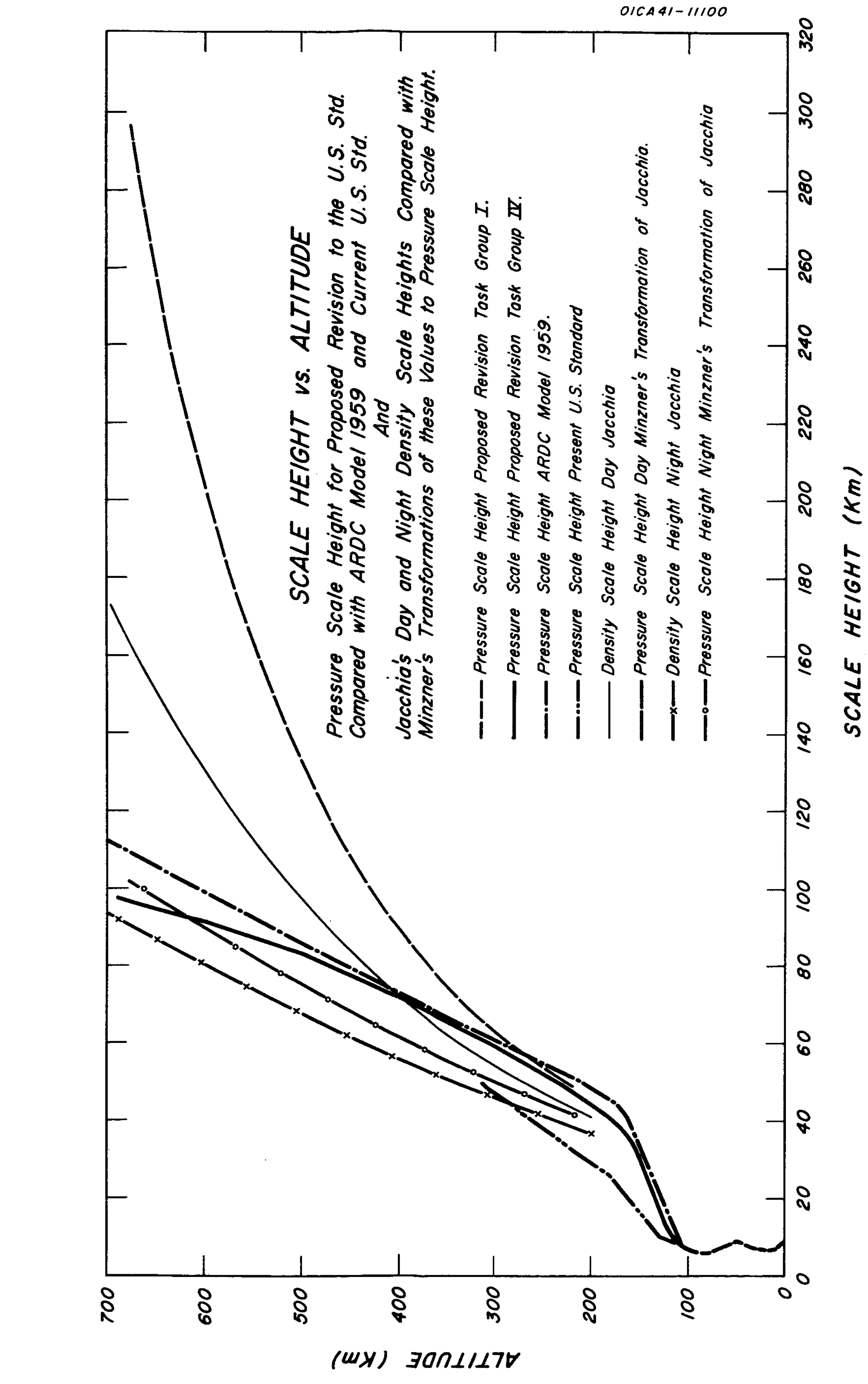
$$T_M = \frac{M_o}{R}\left[\frac{gH_\rho + \dfrac{dg}{dz}H_\rho^{\,2}}{1 - \dfrac{dH_\rho}{dz}}\right] . \tag{16}$$

which may be converted to

$$H_p = \frac{H_\rho + \dfrac{1}{g}\dfrac{dg}{dz}H_\rho^{\,2}}{1 - \dfrac{dH_\rho}{dz}} \tag{17}$$

(Note dg/dZ has a negative value)

Approximating dH_ρ/dZ by values of $\Delta H_\rho/\Delta Z$ from Jacchia's tabulated values of H_ρ, the corresponding values of H_p and T_M were computed by Equations (16) and (17). These are presented on Table 1 and in Figures 10 and 11.



01CA41-11100
SCALE HEIGHT vs. ALTITUDE
Pressure Scale Height for Proposed Revision to the U.S. Std. Compared with ARDC Model 1959 and Current U.S. Std.
And
Jacchia's Day and Night Density Scale Heights Compared with Minzner's Transformations of these Values to Pressure Scale Height.
Pressure Scale Height Proposed Revision Task Group I.
Pressure Scale Height Proposed Revision Task Group IV.
Pressure Scale Height ARDC Model 1959.
Pressure Scale Height Present U.S. Standard
Density Scale Height Day Jacchia
Pressure Scale Height Day Minzner's Transformation of Jacchia.
Density Scale Height Night Jacchia
Pressure Scale Height Night Minzner's Transformation of Jacchia
SCALE HEIGHT (Km)
ALTITUDE (Km)
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
100
200
300
400
500
600
700

Figure 10.

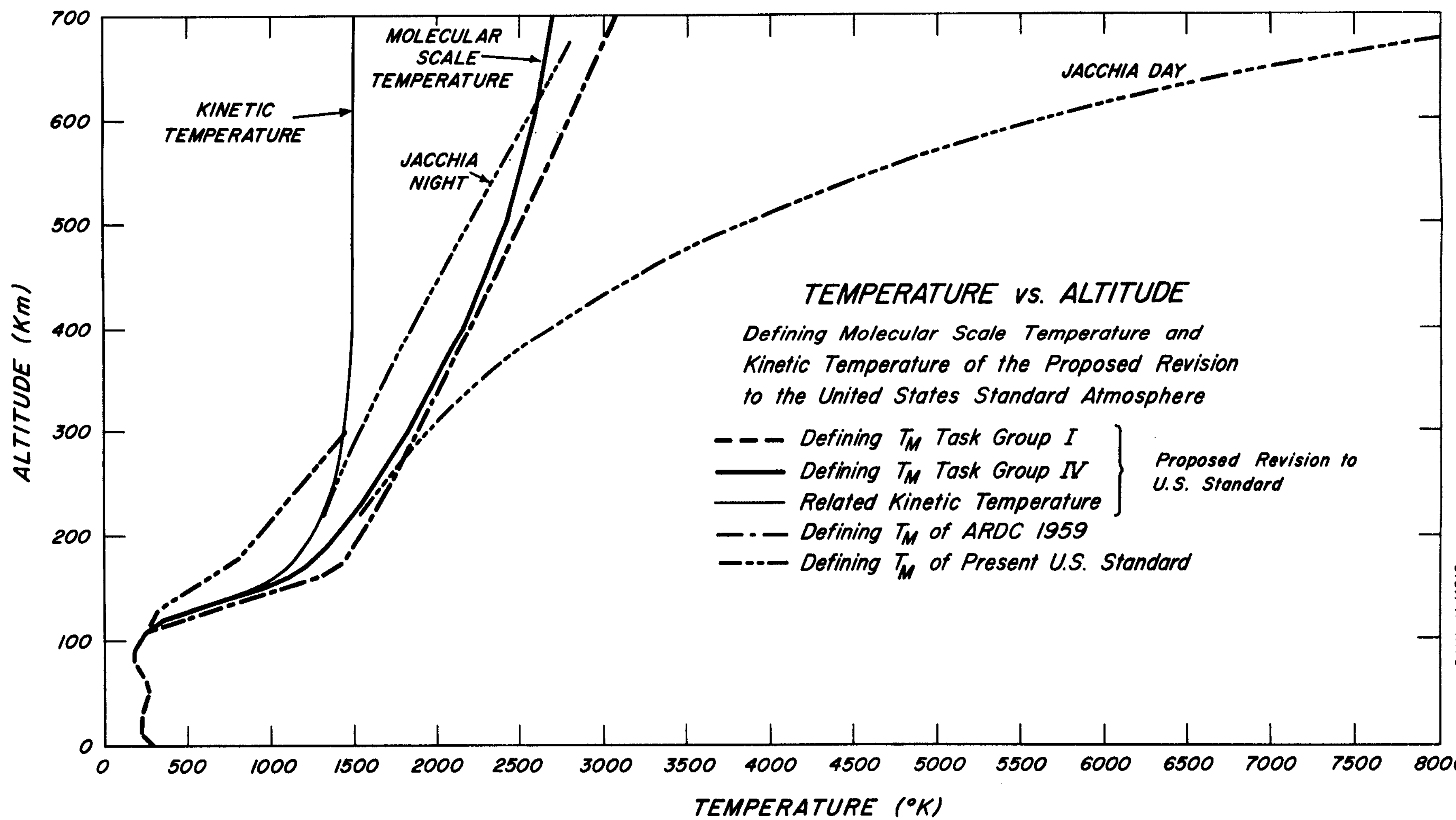

TEMPERATURE vs. ALTITUDE
Defining Molecular Scale Temperature and
Kinetic Temperature of the Proposed Revision
to the United States Standard Atmosphere
Defining T_M Task Group I
Defining T_M Task Group IV
Related Kinetic Temperature
Proposed Revision to U.S. Standard
Defining T_M of ARDC 1959
Defining T_M of Present U.S. Standard
KINETIC TEMPERATURE
MOLECULAR SCALE TEMPERATURE
JACCHIA NIGHT
JACCHIA DAY
ALTITUDE (Km)
TEMPERATURE (°K)
0
100
200
300
400
500
600
700
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
7500
8000
OICA 41-1111 O

Figure 11.

TABLE I

	NIGHT TIME MODEL				DAY TIME MODEL			
	Jacchia	Derived from H_ρ vs Z			Jachia	Derived from H_ρ vs Z		
Z	H_ρ [2]	H_p	T_M	dT_M/dZ	H_ρ	H_p	T_M	dT_M/dZ
Km	Km	Km	^oK	^oK/Km	Km	Km	^oK	^oK/Km
200	36.6				40.7			
220	38.3	41.4	1320	2.49	43.0	48.2	1541	4.65
240	40.0	43.4	1377	3.14	45.5	51.5	1632	4.49
260	41.8	45.4	1432	2.40	48.1	54.9	1730	5.27
280	43.6	47.3	1482	2.55	50.9	58.5	1833	5.03
300	45.4	49.4	1538	3.08	53.8	62.6	1949	6.57
320	47.3	51.7	1601	3.22	57.0	67.1	2080	6.54
340	49.3	54.0	1661	2.83	60.4	71.7	2207	6.20
360	51.3	56.3	1732	3.34	63.9	76.7	2349	8.03
380	53.4	58.7	1786	2.93	67.7	82.8	2518	8.80
400	55.5	61.2	1850	3.50	71.8	89.0	2692	8.61
420	57.7	63.7	1915	3.03	76.1	95.7	2880	10.15
440	59.9	66.3	1982	3.64	80.7	103.0	3080	9.86
460	62.2	69.0	2050	3.13	85.5	110.9	3294	11.61
480	64.5	71.7	2119	3.80	90.6	120.2	3549	13.89
500	66.9	74.6	2189	3.25	96.1	130.8	3841	15.32
520	69.3	77.4	2260	3.87	102.0	142.1	4147	15.43
540	71.8	80.3	2332	3.28	108.2	154.4	4482	17.83
560	74.3	83.1	2397	3.26	114.8	167.7	4838	18.83
580	76.8	86.1	2470	4.02	121.7	182.4	5229	21.32
600	79.4	89.7	2559	4.88	129.0	199.4	5701	25.86
620	82.0	92.9	2624	2.60	136.8	219.4	6220	26.03
640	84.7	95.5	2694	3.43	145.0	241.1	6798	31.75
660	87.4	98.2	2753	2.50	153.7	266.5	7471	35.53
680	90.0	101.2	2819	4.05	162.9	296.6	8268	44.19
700	92.7							

Table I Pressure scale height, molecular scale temperature and molecular-scale-temperature gradient derived from the density-scale-height values of Jacchia's day time and night time diurnal-bulge model of the earth's atmosphere.

D. Validity of Approximations used in Transformation

A question arises as to whether or not it is justifiable to consider $d^2T_M/dz^2 = 0$ in the transformation of Jacchia's tabular H_ρ data. Certainly, in an atmosphere where dT_M/dz is defined to be a constant (as in the Proposed Revision to the U. S. Standard Atmosphere above 90 km) d^2T_M/dz^2 is in fact zero, and Equation (16) relates T_M to the slope of the density scale height vs. altitude function at any point of such a model except at points of discontinuity of dT_M/dz. In the case of a transformation to T_M of H_ρ from a tabulated set of values of H_ρ as those of Jacchia[10], the degree of validity of the assumption of $d^2T_M/dz^2=0$ is indicated below by demonstrating the compatibility of a constant dT_M/dz over an interval Δz and a simultaneously constant dH_ρ/dz over the same interval Δz, as would normally be the tacit assumption in dealing with a tabulated set of values of H_ρ vs. z. If dT_M/dz is constant, $d^2T_M/dz^2 = 0$ and Equation (14), the expression for dH_ρ/dz becomes

$$\frac{dH_\rho}{dz} = \frac{\frac{dT_M}{dz}}{\frac{gM_o}{R} + \frac{dT_M}{dz}} - \frac{T_M \frac{M_o}{R} \frac{dg}{dz}}{\frac{gM_o}{R} + \frac{dT_M}{dz}^2} \tag{18}$$

This expression contains the variables g and dg/dz and, consequently, over the interval Δz where dT_M/dz is assumed constant, dH_ρ/dz cannot be rigorously constant. Evaluating Equation (18) from values obtained in the transformation of Jacchia's data, for the beginning and end of the interval 660 to 680 km for example, the change in slope dH_ρ/dz is seen to be about 0.5% of the average of the interval for the day-time model and about 1.0% of the average for the night-time model.

That is, the slope dH_ρ/dz for the two models over the interval 680 to 690 km departs from a constant by the specified percentages when dT_M/dz is a constant over the 20 km interval. This error is certainly within the error of the original tabulated values of H_ρ and thus the method is justified. These errors reflect an error of 0.7% in the day time T_M or H_ρ and only 0.15% in the night time values of T_M or H_ρ at these altitudes. Numerically this corresponds to errors of 55°K and 2 km respectively for the day-time model, while for the night-time model, the errors would be 4.2°K and 152 meters respectively.

E. Brief Evaluation of Jacchia Model in Terms of Derived Pressure Scale Height and Molecular Scale Temperature

An examination of the graph of Jacchia's values of H_ρ and the corresponding values of H_p suggests that Jacchia's day-time atmosphere is rather unrealistic particularly above 500 km. The value of H_ρ at 700 km is nearly twice that of H_ρ, and corresponds to a T_M of 9600°K, and a value of $dT_M/dz = 50^\circ \text{km}^{-1}$. These values are both extremely high by most present day considerations where the mean molecular weight at 700 km is thought to be about 16. If the mean molecular weight were 8 at this altitude, the Jacchia value of H_ρ might be more acceptable but even then, the continuously increasing value of dT_M/dz from about 4.5°/km to about 50°/km at 700 km, with no indications of d^2T_M/dz^2 approaching zero, suggest a situation which is difficult to explain. Certainly the rate of decrease of M with respect to altitude (see Equation 9) cannot account for such large values of dT_M/dz or for the continuing positive values of d^2T_M/dz^2.

It is suggested that, with essentially no drag data above 700 km, the slope of the Jacchia density vs. altitude curve at high altitudes may well be incorrect and, hence, the values of H_ρ, H_p, T_M and dT_M/dz might also be correspondingly incorrect at these altitudes. This is not to suggest that the magnitude of the diurnal density bulge is any smaller at 700 km than suggested by Jacchia, but rather that the shape of the bulge might somehow be different to reduce the value of d^2T_M/dz^2 if not the value of dT_M/dz at 700 km.

It is possible that if Jacchia had realized the large difference between H_ρ and H_p indicated by the above analysis, he might have found it possible and desirable to make some modifications to his model.

4. Proposed Revision to the U. S. Standard Atmosphere 90 to 200 km Report of Task Group II

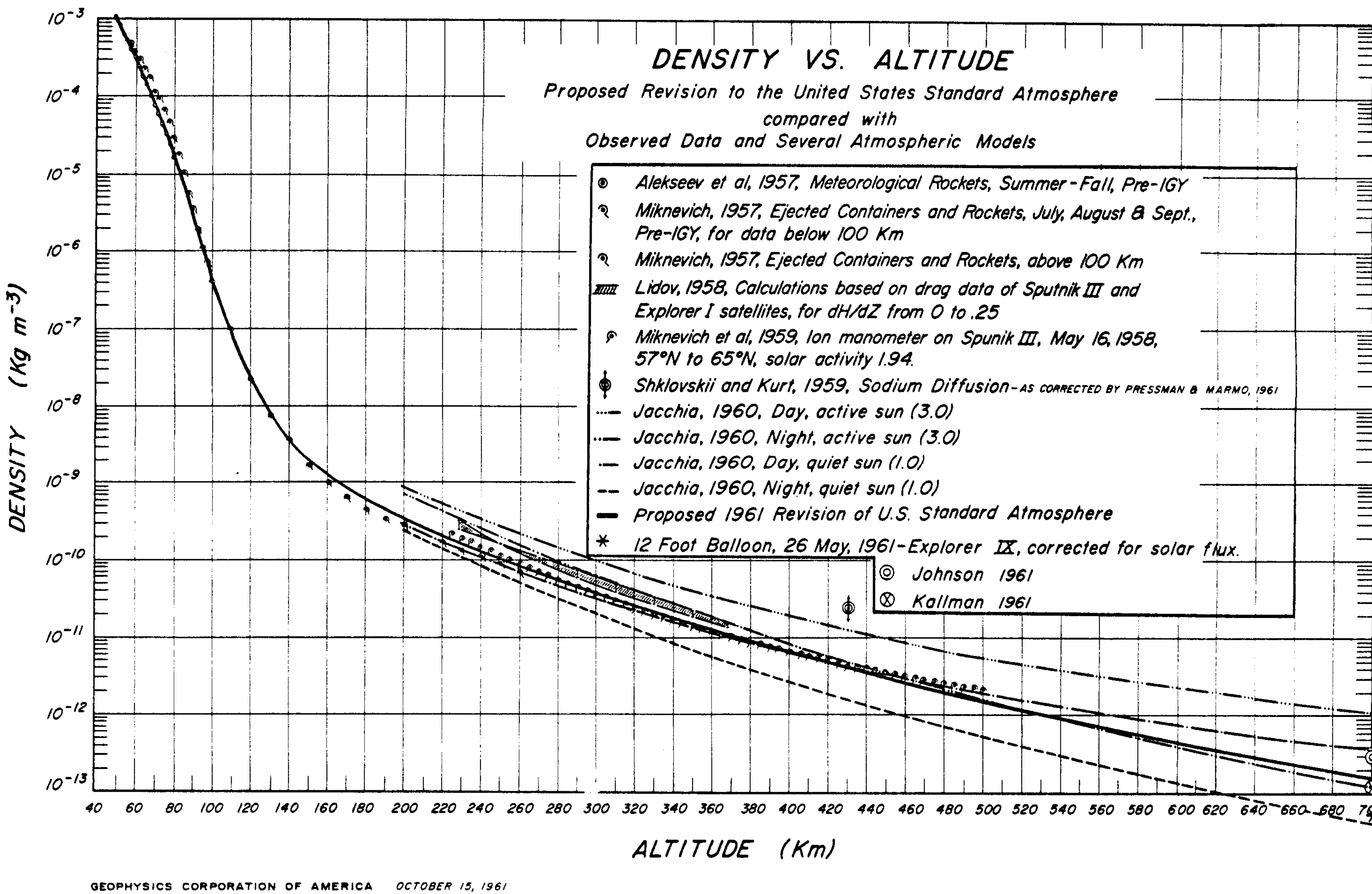
Following the January meeting of the Working Group of COESA, the members of Task Group II, comprising people from NAAS, Geophysics Corporation of America and AFCRL, worked together to establish a part of the defining T_M vs. z function of a Proposed Revision to the U. S. Standard Atmosphere. On the basis of this definition the balance of the work represented by the Report of Task Group II was performed mainly under the contract herein reported. Consequently, the Report of Task Group II is presented completely as Appendix A of this report.

5. Excerpts of Interim Report of Task Group IV

A. Defining Properties of the Proposed Standard Atmosphere 90 to 700 km

Contract NAS5-270 supported a very small amount of the early work of Task Group IV of COESA, but the major part of the work was supported by an Air Force contract. Consequently, only a summary of the results of Task Group IV is given in this report. As of this writing, an interim report has been circulated among the members of Task Group IV for final approval before submission to the Working Group of COESA. The model, developed by Champion and Minzner, which is now awaiting approval, is represented by the following table and three figures extracted directly from Scientific Report IV[17] under contract AF 19(628)-231.

Table II presents the defining properties of the Proposed Standard Atmosphere from 90 to 700 km, while Figures 12, 13 and 14 compare the density pressure and molecular weight of the Proposed Standard Atmosphere with previous models for the same altitude range. The pressure scale height and the temperature of the Proposed Standard Atmosphere were already presented in Figures 10 and 11 respectively, along with the corresponding parameters of the Jacchia models.



DENSITY VS. ALTITUDE
Proposed Revision to the United States Standard Atmosphere
compared with
Observed Data and Several Atmospheric Models
Alekseev et al, 1957, Meteorological Rockets, Summer-Fall, Pre-IGY
Miknevich, 1957, Ejected Containers and Rockets, July, August & Sept., Pre-IGY, for data below 100 Km
Miknevich, 1957, Ejected Containers and Rockets, above 100 Km
Lidov, 1958, Calculations based on drag data of Sputnik III and Explorer I satellites, for dH/dZ from 0 to .25
Miknevich et al, 1959, Ion manometer on Spunik III, May 16, 1958, 57°N to 65°N, solar activity 1.94
Shklovskii and Kurt, 1959, Sodium Diffusion-AS CORRECTED BY PRESSMAN & MARMO, 1961
Jacchia, 1960, Day, active sun (3.0)
Jacchia, 1960, Night, active sun (3.0)
Jacchia, 1960, Day, quiet sun (1.0)
Jacchia, 1960, Night, quiet sun (1.0)
Proposed 1961 Revision of U.S. Standard Atmosphere
12 Foot Balloon, 26 May, 1961-Explorer IX, corrected for solar flux.
Johnson 1961
Kallman 1961
DENSITY (Kg m^-3)
ALTITUDE (Km)
GEOPHYSICS CORPORATION OF AMERICA OCTOBER 15, 1961

Figure 12.

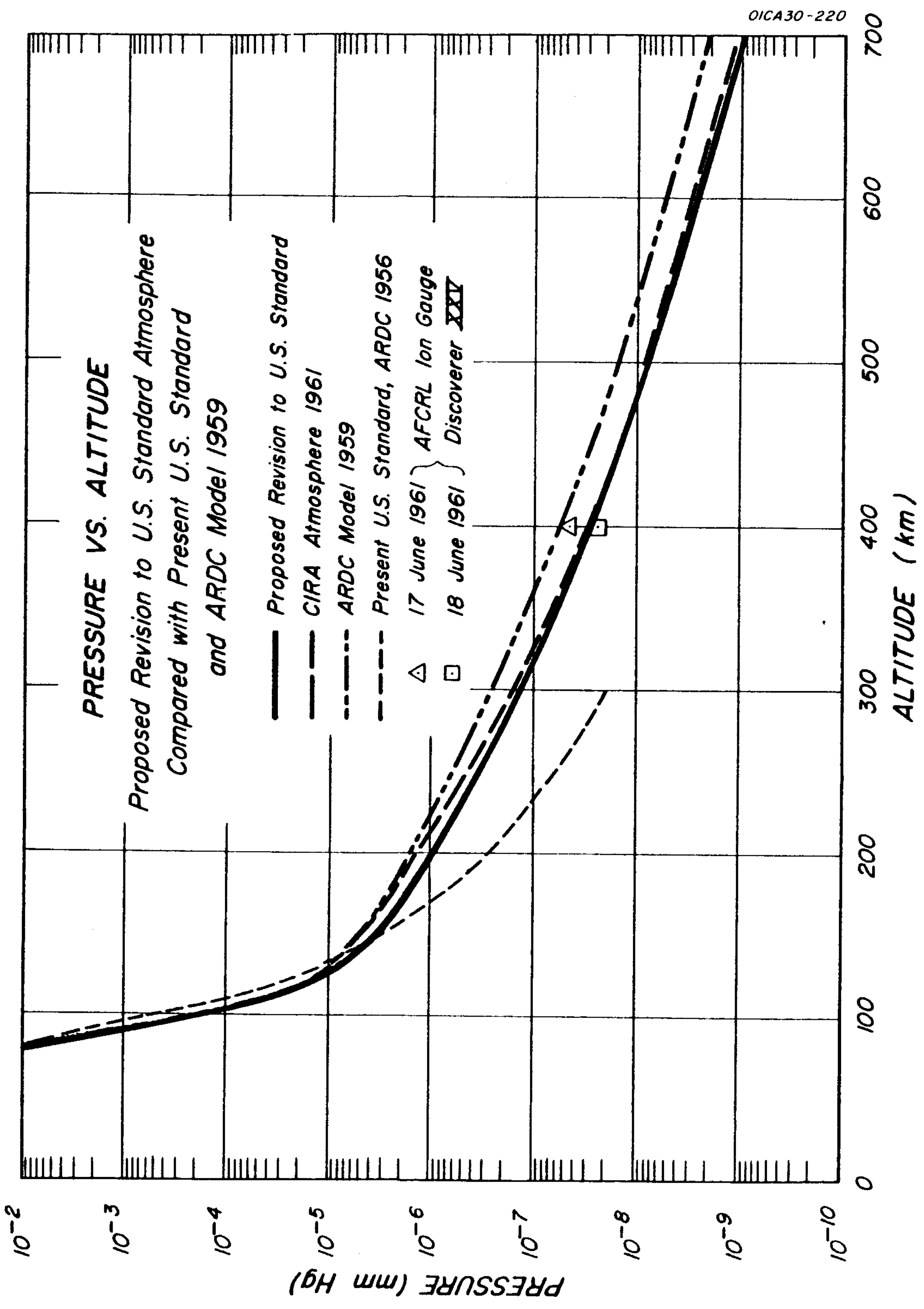
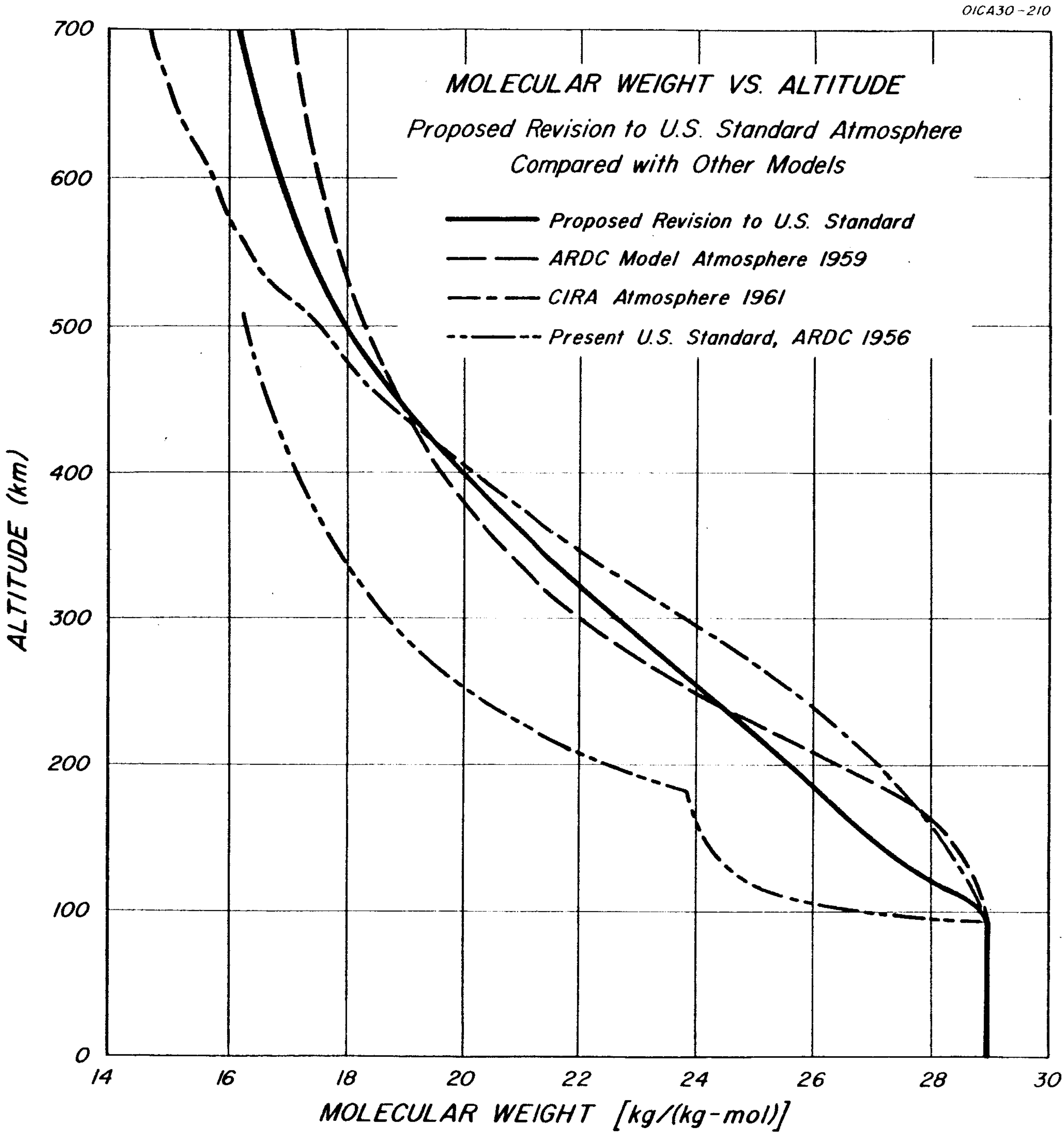

PRESSURE VS. ALTITUDE
Proposed Revision to U.S. Standard Atmosphere
Compared with Present U.S. Standard
and ARDC Model 1959
Proposed Revision to U.S. Standard
CIRA Atmosphere 1961
ARDC Model 1959
Present U.S. Standard, ARDC 1956
17 June 1961 } AFCRL Ion Gauge
18 June 1961 } Discoverer XXV
01CA30-220
PRESSURE (mm Hg)
ALTITUDE (km)
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
0
100
200
300
400
500
600
700

Figure 13.



01CA30-210
MOLECULAR WEIGHT VS. ALTITUDE
Proposed Revision to U.S. Standard Atmosphere
Compared with Other Models
Proposed Revision to U.S. Standard
ARDC Model Atmosphere 1959
CIRA Atmosphere 1961
Present U.S. Standard, ARDC 1956
700
600
500
400
300
200
100
0
ALTITUDE (km)
14
16
18
20
22
24
26
28
30
MOLECULAR WEIGHT [kg/(kg-mol)]

Figure 14.

TABLE II

DEFINING PROPERTIES OF THE PROPOSED STANDARD ATMOSPHERE

z km	L °K/km	T_M °K	M	T
90	+ 3	180.65	28.966	180.65
100	+ 5	210.65	28.88	210.02
110	+10	260.65	28.56	257.00
120	+20	360.65	28.07	349.49
150	+15	960.65	26.92	892.79
160	+10	1110.65	26.66	1022.2
170	+ 7	1210.65	26.40	1103.4
190	+ 5	1350.65	25.85	1205.4
230	+ 4	1550.65	24.70	1322.3
300	+ 3.3	1830.65	22.66	1432.1
400	+ 2.6	2160.65	19.94	1487.4
500	+ 1.7	2420.65	17.94	1499.2
600	+ 1.1	2590.65	16.84	1506.1
700		2700.65	16.17	1507.6

z = Geometric Altitude

T_M = Molecular Scale Temperature = TM_o/M

T = Kinetic Temperature

M = Mean Molecular Weight

M_o = Sea Level Value of M

L = dT_M/dz, Gradient of Molecular Scale Temperature

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APPENDIX A

STANDARD ATMOSPHERE REVISION 90 TO 200 KM

Interim Report of Task Group II

Raymond A. Minzner[1], Kenneth S.W. Champion[2], H. Lee Kyle[3] and Herman E. LaGow[3]

April 7, 1961

1. Background

At a meeting of the Working Group of the Committee on Extension to the Standard Atmosphere (COESA) held at M.I.T. in Cambridge, Massachusetts, on January 16-17, 1961, a decision was made to revise the existing U.S. Standard Atmosphere above 20 km within specified or implied boundry conditions. This decision was augmented by the appointment of three task groups, each group to be responsible for the preparation of a particular altitude segment of this revised, scientifically-up-to-date, U.S. Standard Atmosphere. Task Group I was responsible for the region from 20 to 90 km; Task Group II, for the region from 90 to 200 km; and Task Group III, for the region above 200 km.

In addition to the first three authors of this report, Task Group II consisted of Nelson W. Spencer of Goddard Space Flight Center, NASA; Phillip W. Mange of Naval Research Laboratories; and Richard A. Hord of Langley Research Center, NASA. Mr. Kyle, while not a formal member of the

1. Geophysics Corporation of America

2. Air Force Cambridge Research Laboratories

3. Goddard Space Flight Center, NASA

task group, worked closely with the group and handled the programing of the IBM machine computations. The proposal prepared by Task Group II represents the results of a closely coordinated effort between members of Geophysics Corporation of America, Air Force Cambridge Research Laboratories, and Goddard Space Flight Center of NASA, plus considerable contributions by the members from NRL and Langley Research Center, NASA, for which the authors are grateful.

The early history of standard atmospheres since the 1920's is adequately covered in the report of Task Group I. The current U.S. Standard Atmosphere, based on rocket data available in 1955, (all for altitudes below 160 km) and extrapolated to 300 km without the benefit of observed data, was found to be considerably in error above 160 km, when a number of satellite-derived densities became available in early 1958. The ARDC Model Atmosphere 1959 based on the then-available atmospheric data, including densities to 700 km and measured values of composition to 200 km, served as a revision of the U.S. Standard Atmosphere above 53 km.

Great advances in the understanding of the variability of the density of the atmosphere above 200 km have since been made, but additional data and study which produced these advances have produced but little change in the magnitude of the average values of the atmospheric properties, particularly for the altitude region of 100 to 200 km. It is not surprising, therefore, that the pressures and densities of the proposal of Task Group II do not differ greatly from those of the ARDC Model 1959. The reasons for not adopting the ARDC Model 1959 as the revision of the U.S. Standard, stem principally from small difficulties in the temperature-altitude profile for altitudes between 20 and 35 km. Since no model can be revised at low altitudes without effecting, to some degree, the upper part of the model, the recommendation to re-examine the entire model above 20 km was adopted.

2. Boundary Conditions

During the course of the meeting of January 16-17, 1961, the various presentations, discussions, motions and agreements amounted to a number of boundry conditions imposed upon the several task groups, not the least of which was the requirement for continuity between the work of the several task groups. The various boundry conditions as applicable to Task Group II are summarized in three groups: (a) the rocket and satellite data determining the model between 90 and 200 km, (b) the 90 km values imposed by Task Group I, and (c) the values of density and temperature at 200 km suggested as a continuity point for Task Groups II and III by a coordination meeting in Washington.

The 20 to 90 km model of Task Group I is characterized at its upper end by an isothermal layer from 79.000 standard geopotential kilometers, km' (79.994 geometric kilometers, km) to 88.743 km' (90.000 km) at which altitude the molecular scale temperature T_M, the pressure p, and the density ρ, have the following values:

	cgs Units	mks Units	Mixed Units
T_M	180.65 ^{o}K	180.65 ^{o}K	180.65 ^{o}K
p	1.6437 dynes cm^{-2}	1.6437 x 10^{-3} nt m^{-2}	1.2329 x 10^{-3} mm
ρ	3.1698 x 10^{-9} gr cm^{-3}	3.1698 x 10^{-6} kg m^{-3}	3.1698 x 10^{-3} gr m^{-3}

These must be the starting values of the adjacent segment from 90 to 200 km.

At 200 km, the objective of the task group is to reach a density value of about 3.3×10^{-10} kg m^{-3} $\pm$ 10% and a value of T_M = 1400 ^{o}K $\pm$ 5%. Densities from reliable rocket measurements range from about 1.4×10^{-10} to 7×10^{-10} kg m^{-3}, while densities derived from satellite drag at this altitude range from about 2×10^{-10} to 6×10^{-10} kg m^{-3}. Jacchia's variable-density model at 200 km suggests a mean-low value of 2.3×10^{-10} kg m^{-3} for ψ' = 180^{o} and F_{20} = 1, and a mean-high value of 8.2×10^{-10} kg m^{-3} for ψ' = 0^{o} and F_{20} = 3. The difference between these extremes would increase for more extreme values of F_{20}. The actual decrease in density between 90 and 200 km depends, of course, upon a function of $\int T_M^{-1} dZ$ between these altitudes as well as upon a function of the ratio T_{M200}/T_{M90}. Hence, the ρ (Z) function differs for each modification of the $T_M(Z)$ function. The 200-km value of density in the Task-Group-II proposal is 3.41×10^{-10} kg m^{-3}, or 3.41×10^{-10} gr m^{-3}.

The data available for determining the model between 90 and 200 km consist principally of gauge-determined values of pressure and density with some densities determined from satellite drag above 160 km. Above 110 km, the rocket data consist principally of densities with values of p and T_M inferred. The more recent, and hence more reliable data, apply principally to 59 ^{o}N latitude, and an attempt was made to subjectively adjust the model for mid-latitude conditions. The results of diffusion and turbulence measurements of sodium and other chemical release experiments also influenced the model, particularly in establishing the shape of the T_M function near

115 km, where a sharp increase in the temperature gradient occurs.

The results from the rocket-grenade experiments and the falling-sphere experiments which dominated the data between 40 and 90 km also influenced the model to altitudes as high as 100 km through the upward propagation effects of the hydrostatic equation.

The inferred values of T_M associated with the several rocket flights suggest large variations above 150 km with values at 200 km varying between 1400 and 3000 ^{o}K. Because of the integral of the inverse temperature function in the density-altitude relationship, such large variations of T_M near 200 km, where T_M is large, can be compensated for by relatively small variations in T_M at lower altitudes where T_M is small. Thus, the density-altitude function is relatively insensitive to variations of the $T_M(Z)$ function above 150 km as compared with similar variations between 90 and 120 km. The stated attempts to have the model above 200 km represent conditions somewhere between the extremes of midnight and midday with $T_M = 1400^{o}$ is well matched by the 200-km value of the Task-Group-II proposal, 1390 ^{o}K, a value falling about midway between those corresponding to Jacchia's night-time and day-time models.

3. Defining Relationships

Contrary to the situation in the existing U.S. Standard Atmosphere and in the ARDC Model Atmospheres, 1956 and 1959, or in any other previous model, the altitude parameter of the Standard Atmosphere Revision will not be uniform over the entire altitude range. Geopotential is to be the argument from 0 to 79.006 km' (0 to 80 km) and geometric altitude above

80 km, by vote of the Working Group of COESA. Thus, the defining temperature function which is intended to be a series of continuous linear segments will be linear in terms of geopotential below 80 km and linear in terms of geometric altitude above 80 km. The cross-over point has been selected at an altitude where geopotential altitude and geometric altitude differ numerically by nearly one kilometer, and in an isothermal layer where the T_M function may be linear simultaneously in both systems of altitude measure.

Since T_M is a linear function of geopotential below 80 km, the differential form of the hydrostatic equation may be simply integrated with the variation of gravity effectively vanishing into geopotential. Above 80 km, however, where T_M is defined linearly in terms of geometric altitude, the variation of gravity must be accounted for by some functional relationship. Under these circumstances, the simplicity sought for, by the use of a linear temperature function is lost due to the gravity function, and numerical or other methods of calculation must be employed. Thus, two different sets of computational proceedures will be required in preparing the detailed tables of this standard, one set below 80 km and a different set above 80 km.

As in previous U.S. Standard Atmospheres, the defining temperature parameter of this revision is molecular scale temperature T_M in ^{o}K which is defined as

$$T_M \equiv \frac{T}{M} \cdot M_o \qquad \text{(A-1)}$$

where T is kinetic temperature ^{o}K

M is mean molecular weight of the air (dimensionless) and

M_o is the sea-level value of M.

Thus, at altitudes below about 90 km, where M is generally considered to be essentially equal to M_o, T_M is equal to T, and continuity with the ICAO Standard Atmosphere prevails. At altitudes where $M \neq M_o$, the parameter T_M is a convenient one since the slope of the log-pressure curve, scale height, and the speed of sound may all be related by T_M even though neither T nor M are known independently. In addition, T_M may be readily measured. Thus:

$$\frac{d\ln p}{dZ} = \frac{-g\,M}{R^*T} = \frac{-g\,M_o}{R^*\,T_M} = \frac{-1}{H_S}\,, \tag{A-2}$$

and

$$c_S{}^2 = \frac{\gamma p}{\rho} = \frac{\gamma R^* T}{M} = \frac{\gamma R^* T_M}{M_o}\,. \tag{A-3}$$

Therefore,

$$T_M = c_S{}^2\,\frac{M_o}{\gamma R^*} \quad \frac{1}{g}\,\frac{dZ}{d\ln p}\,\frac{R^*}{M_o} \quad \frac{H_S}{g}\,\frac{R^*}{M_o} \tag{A-4}$$

No defining relationship for molecular weight has yet been finalized by Task Group II. There have been relatively few measurements of the neutral constituents of the atmosphere above 90 km. The principal measurements have been made with rocket-borne mass spectrometers by Townsend and Meadows and solar ultraviolet absorption studies by Kupperian, Byram and Friedman. Unfortunately, the results of these two different types of measurement are not in good agreement. Charles Johnson has recently pointed out some of the problems involved in the mass spectrometer measurements. Mean molecular weights of 28.6 at 120 km, 28.2 at 150 km and 25.3 at 200 km have been obtained with a mass spectrometer, whereas values of 26.0 at 120 km and

25.3 at 130 km were obtained with ultraviolet absorption equipment. With such a wide variation of the measured results, it seems necessary to take an intermediate set of values, obtaining as much guidance as possible from the theory of processes known to occur in this region of the atmosphere.

Up to an altitude of about 120 km, chemical release studies show the existence of persistent turbulence. Thus, Champion suggested that this mixing would result in little change in composition up to this altitude, and that a mean molecular weight of approximately 28.0 would be appropriate. A set of molecular weights was chosen empirically between 90 and 120 km, and Mange calculated the molecular weights between 120 km and 200 km assuming that diffusive separation was the only important process in this region. The values are listed in Table A-3 under M_1. Mange repeated this calculation assuming that the mean molecular weight at 120 km was 27.0. These values are listed under M_2.

Champion investigated the assumption that photo-dissociation could be ignored near 120 km with the following result. From Hinteregger's most recent data, the flux of the Schumann continuum between 1400 and 1600 Å at the top of the atmosphere is 10^{12} photons cm^{-2} sec^{-1}. Of this flux, it is estimated that 4×10^{11} photons cm^{-2} sec^{-1} are absorbed in the atmosphere between 120 and 130 km. This results in approximately 4×10^{5} dissociations cm^{-3} sec^{-1} at 125 km and a photo-dissociation time constant of about 4×10^{3} sec. On the other hand, if the diffusion coefficient at this altitude is taken to be 10^{4} m^{2} sec^{-1}, the diffusion time constant is of the order of 10^{4} to 10^{5} sec. If these estimates are correct, the effects of photo-dissociation cannot be ignored below an altitude of 140 km to 150 km. The values listed under M_3 in Table A-3 were calculated by Champion assuming a mean molecular weight of 28.0 at 120 km with diffusive separation above and with a correction for the effect of photo-dissociation between 120 km and 140 km.

4. Conclusions

Table A-1 attached compares the proposed Standard Atmosphere Revision between 90 and 200 km with the present U.S. Standard Atmosphere and the ARDC Model Atmosphere 1959 by means of values of the temperature gradients for various altitude intervals, as well as the values of T_M at those altitudes where values of the gradients change. The proposed model represents that one of the many computed which best fits the many objective and subjective boundry conditions established. Other models could most likely be found which would fit these conditions even better, but time has precluded further investigation.

Figure A-1 graphically compares the $T_M(Z)$ function for this proposed revision with observed values of T_M and with the ARDC Model Atmosphere 1959 for altitudes above 90 km. Figures A-2 and A-3 graphically compare the Task-Group-II-Proposal values of p and ρ, respectively, with observed values of rocket and satellite measurements, including Russian data, and with the ARDC Model 1959. Figure A-4, showing $1/T_M$ as a function of altitude permits the immediate qualitative evaluation of $\int T_M^{-1}\, dZ$ for any altitude interval as the area under the curve for that altitude interval. Hence, it illustrates the relative importance of variations of T_M on the altitude variation of pressure under conditions when T_M is small as compared to the situation when T_M is large.

Table A-2 presents the Task-Group-II Proposal numerically by listing values of density, pressure, scale height, and molecular scale temperature as a function of altitude.

Table A-3 contains the alternative values of molecular weight calculated by Mange and Champion, together with the kinetic temperatures that they imply in terms of the molecular scale temperatures recommended in Table A-2.

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TABLE A-1

TABULATIONS OF DEFINING TEMPERATURE FUNCTIONS OF
CURRENT AND PROPOSED STANDARD ATMOSPHERES 90 to 200 km

Recommended by Task Group II

		U.S. Std. 1958		ARDC 1959		Proposed 1961	
H	Z	T_M	L_M'	T_M	L_M'	T_M	L_M
88.744	90.000					180.65	--
90.000	91.293	196.86	--	165.66	--		+2
98.451	100.000				+4.0	200.65	--
105.000	106.764		+3.5	225.66	--		+4
108.129	110.					240.65	--
							+6
112.957	115.					270.65	--
126.000	128.548	--			+20		+25
127.395	130.					645.65	--
							+20
151.311	155.					1145.65	--
160.	164.131		+10.0	1325.66	--		+10
160.828	165.				+10	1245.65	--
170.	174.671			1425.66	--		+5
175.	179.954	812.86	--				
175.043	180.				+5	1320.65	--
							+3.5
193.899	200.		+5.8			1390.65	--
200.	206.497			1575.66	--		
300.	314.862	1537.86	--		+35	?	?
700.				3325.66	--		

H = Geopotential alt. in std. geopotential kilometers (km')
Z = Geometric alt. in kilometers
T_M = Molecular scale temp. = $(T/M \cdot M_o)$ in ^oK
T = Kinetic temp. in ^oK
M = Molecular weight (dimensionless)
M_o = Sea-level value of M
L_M' = dT_M/dH, molecular scale temperature gradient in $^oK/km'$
L_M = dT_M/dZ, molecular scale temperature gradient in $^oK/km$

TABLE A-2

ATMOSPHERIC PROPERTIES VS ALTITUDE 90 to 200 km

Recommended by Task Group II

Altitude Geometric Z km	Density ρ gm cm^{-3}	Pressure p dynes cm^{-2}	Scale Height H_S km	Molecular Scale Temperature T_M °K
90.0	3.170×10^{-9}	1.644×10^{0}	5.437	180.6
92.0	2.156	1.143	5.561	184.6
94.0	1.479	8.009×10^{-1}	5.685	188.6
96.0	1.023	5.656	5.809	192.6
98.0	7.127×10^{-10}	4.023	5.933	196.6
100.0	5.004	2.883	6.058	200.6
102.0	3.482	2.086	6.303	208.6
104.0	2.457	1.528	6.549	216.6
106.0	1.756	1.132	6.795	224.6
108.0	1.270	8.482×10^{-2}	7.041	232.6
110.0	9.287×10^{-11}	6.416	7.288	240.6
112.0	6.769	4.910	7.656	252.6
114.0	5.007	3.804	8.025	264.6
116.0	3.527	2.994	8.971	295.6
118.0	2.456	2.437	10.495	345.6
120.0	1.796	2.040	12.020	395.6
122.0	1.363	1.744	13.548	445.6
124.0	1.066	1.516	15.078	495.6
126.0	8.532×10^{-12}	1.337	16.609	545.6
128.0	6.966	1.191	18.143	595.6
130.0	5.781	1.072	19.679	645.6
132.0	4.933	9.710×10^{-3}	20.909	685.6
134.0	4.248	8.848	22.143	725.6
136.0	3.687	8.104	23.378	765.6
138.0	3.224	7.456	24.616	805.6
140.0	2.837	6.888	25.852	845.6
142.0	2.512	6.387	27.092	885.6
144.0	2.236	5.942	28.334	925.6
146.0	2.000	5.545	29.577	965.6
148.0	1.798	5.190	30.822	1005.6
150.0	1.622	4.870	32.065	1045.6
152.0	1.470	4.581	33.313	1085.6
154.0	1.337	4.319	34.563	1125.6
156.0	1.230	4.080	35.507	1155.6
158.0	1.143	3.858	36.140	1175.6
160.0	1.064	3.653	36.779	1195.6
162.0	9.017×10^{-13}	3.461	37.418	1215.6

TABLE A-2 (continued)

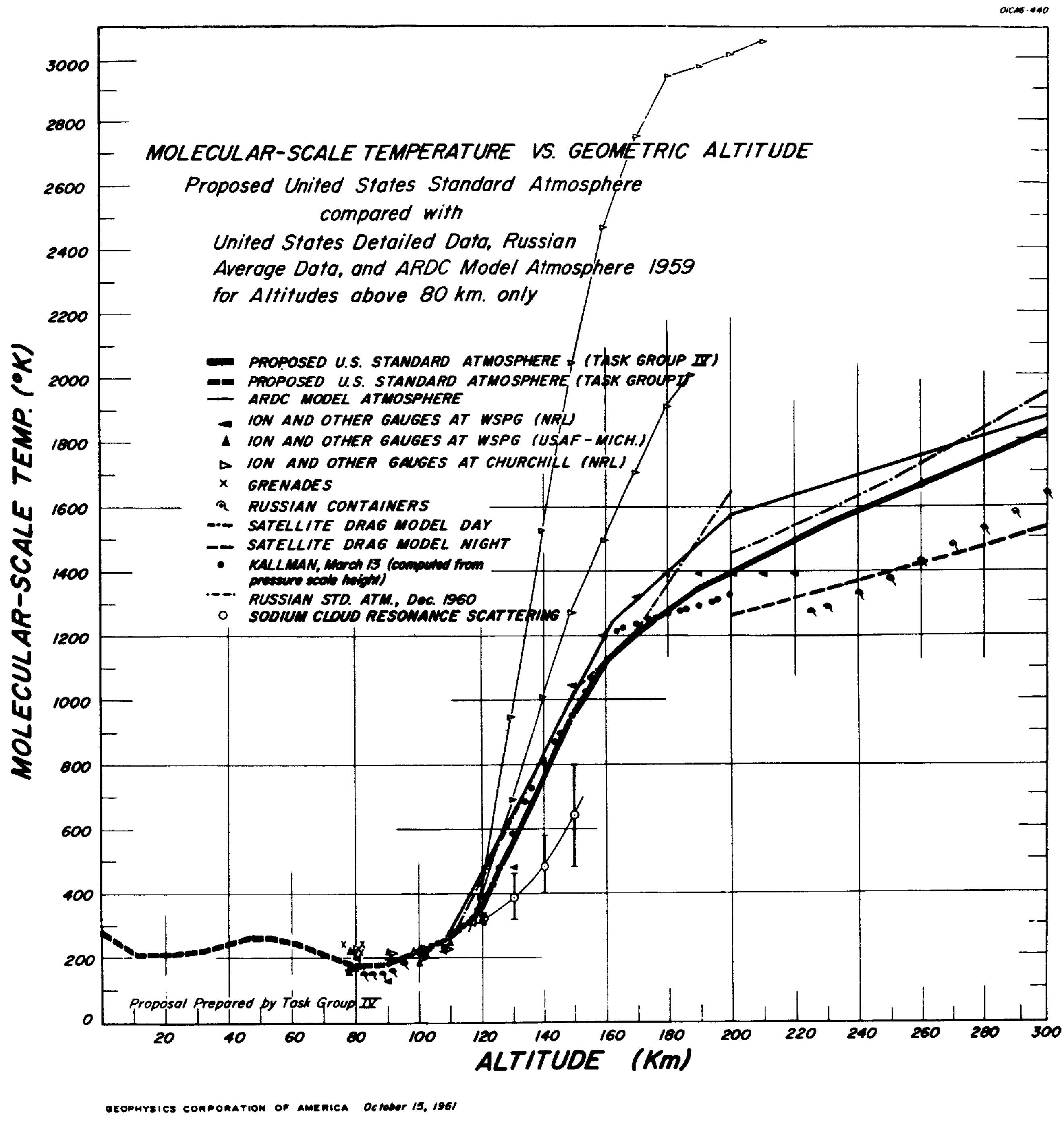
Altitude Geometric Z km	Density ρ gm cm^{-3}	Pressure p dynes cm^{-2}	Scale Height H_S km	Molecular Scale Temperature T_M °K
164.0	9.253	3.282	38.054	1235.6
166.0	8.677	3.115	38.541	1250.6
168.0	8.175	2.959	38.874	1260.6
170.0	7.706	2.811	39.208	1270.6
172.0	7.267	2.672	39.538	1280.6
174.0	6.856 x 10^{-13}	2.540 x 10^{-3}	39.872	1290.6
176.0	6.472	2.417	40.207	1300.6
178.0	6.112	2.300	40.538	1310.6
180.0	5.775	2.190	40.874	1320.6
182.0	5.471	2.085	41.117	1327.6
184.0	5.185	1.987	41.356	1334.6
186.0	4.915	1.893	41.600	1341.6
188.0	4.661	1.805	41.844	1348.6
190.0	4.421	1.721	42.084	1355.6
192.0	4.195	1.641	42.329	1362.6
194.0	3.981	1.565	42.574	1369.6
196.0	3.780	1.494	42.815	1376.6
198.0	3.590	1.426	43.061	1383.6
200.0	3.410	1.361	43.307	1390.6

TABLE A-3

MOLECULAR WEIGHTS AND KINETIC TEMPERATURES VS ALTITUDE
90 to 200 km COMPATABLE WITH MOLECULAR SCALE
TEMPERATURES

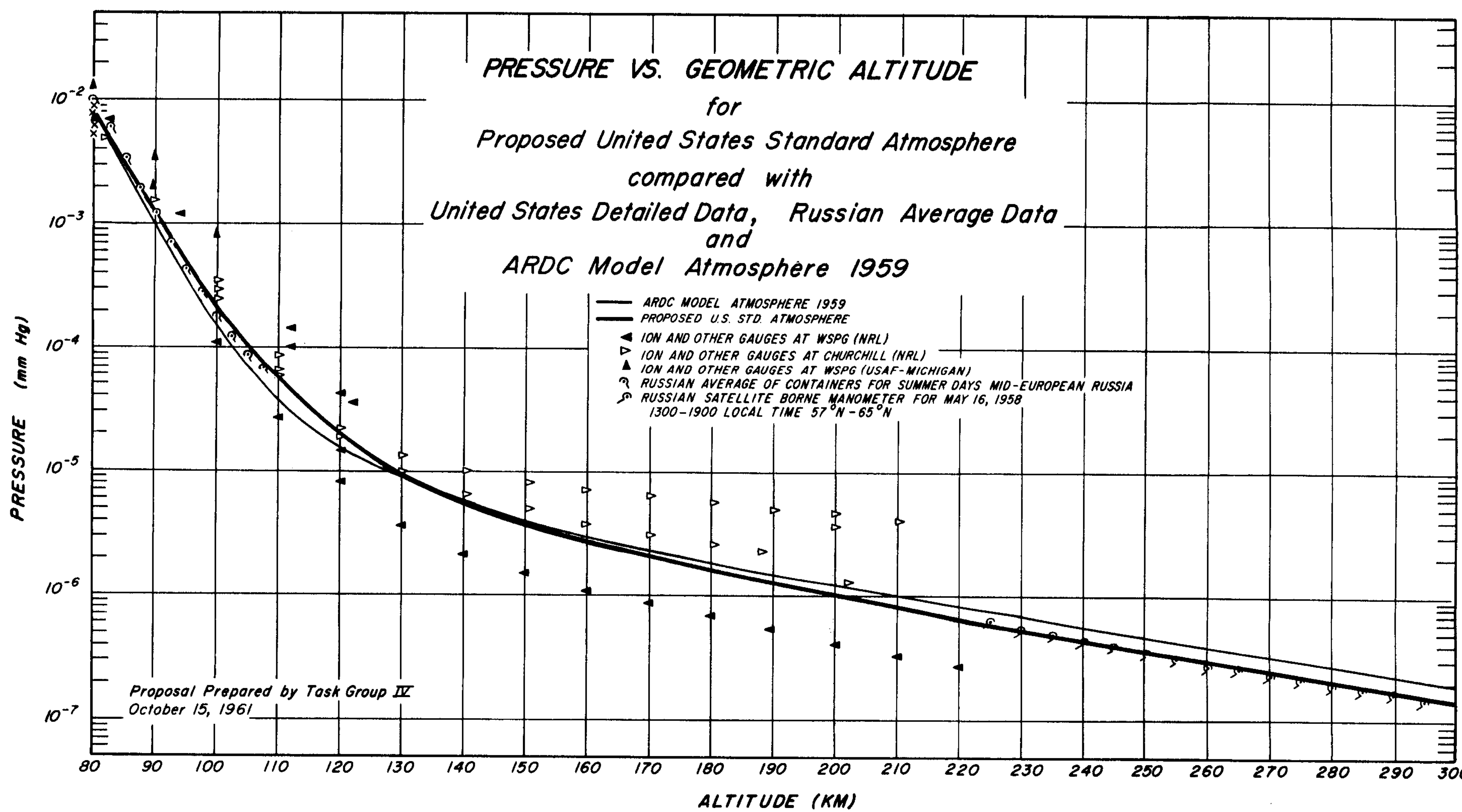
Recommended by Task Group II

Altitude (geom Km)	M_1	T_1 (°K)	M_2	T_2 (°K)	M_3	T_3 (°K)
90	28.966	180.6	28.966	180.6	28.966	180.6
100	28.90	200.1	28.55	197.7	28.90	200.1
110	28.50	236.7	27.70	230.1	28.50	236.7
120	28.01	382.4	27.01	368.8	28.00	382.4
130	27.69	617.4	26.46	589.8	27.38	610.2
140	27.43	799.4	26.01	757.8	26.96	787.0
150	27.19	981.4	25.62	925.8	26.62	960.9
160	26.98	1113.4	25.26	1042.7	26.34	1087.2
170	26.77	1174.4	24.91	1092.7	26.07	1143.6
180	26.55	1210.4	24.56	1119.7	25.79	1175.8
190	26.32	1231.4	24.21	1132.3	25.51	1193.8
200	26.09	1252.4	23.84	1144.9	25.22	1210.8



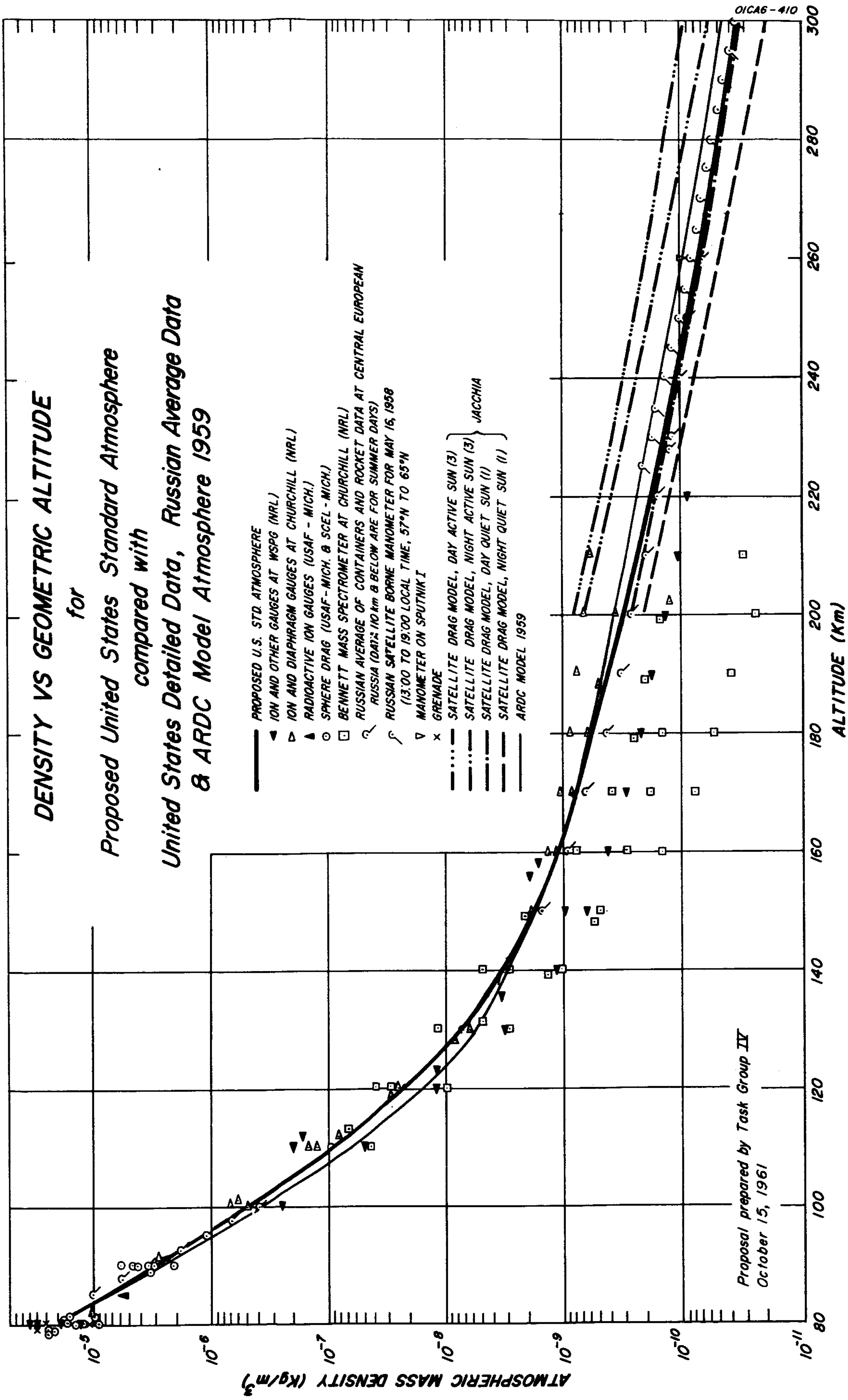
OICAS-440
MOLECULAR-SCALE TEMPERATURE VS. GEOMETRIC ALTITUDE
Proposed United States Standard Atmosphere
compared with
United States Detailed Data, Russian
Average Data, and ARDC Model Atmosphere 1959
for Altitudes above 80 km. only
PROPOSED U.S. STANDARD ATMOSPHERE (TASK GROUP IV)
PROPOSED U.S. STANDARD ATMOSPHERE (TASK GROUP II)
ARDC MODEL ATMOSPHERE
ION AND OTHER GAUGES AT WSPG (NRL)
ION AND OTHER GAUGES AT WSPG (USAF-MICH.)
ION AND OTHER GAUGES AT CHURCHILL (NRL)
GRENADES
RUSSIAN CONTAINERS
SATELLITE DRAG MODEL DAY
SATELLITE DRAG MODEL NIGHT
KALLMAN, March 13 (computed from pressure scale height)
RUSSIAN STD. ATM., Dec. 1960
SODIUM CLOUD RESONANCE SCATTERING
MOLECULAR-SCALE TEMP. (°K)
3000
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
Proposal Prepared by Task Group IV
20 40 60 80 100 120 140 160 180 200 220 240 260 280 300
ALTITUDE (Km)
GEOPHYSICS CORPORATION OF AMERICA October 15, 1961

Figure A-1.



GEOPHYSICS CORPORATION OF AMERICA

Figure A-2.



OICA6-410
DENSITY VS GEOMETRIC ALTITUDE
for
Proposed United States Standard Atmosphere
compared with
United States Detailed Data, Russian Average Data
& ARDC Model Atmosphere 1959
PROPOSED U.S. STD. ATMOSPHERE
ION AND OTHER GAUGES AT WSPG (NRL)
ION AND DIAPHRAGM GAUGES AT CHURCHILL (NRL)
RADIOACTIVE ION GAUGES (USAF - MICH.)
SPHERE DRAG (USAF-MICH. & SCEL-MICH.)
BENNETT MASS SPECTROMETER AT CHURCHILL (NRL)
RUSSIAN AVERAGE OF CONTAINERS AND ROCKET DATA AT CENTRAL EUROPEAN RUSSIA (DATA 110 km & BELOW ARE FOR SUMMER DAYS)
RUSSIAN SATELLITE BORNE MANOMETER FOR MAY 16, 1958 (13:00 TO 19:00 LOCAL TIME, 57°N TO 65°N
MANOMETER ON SPUTNIK I
GRENADE
SATELLITE DRAG MODEL, DAY ACTIVE SUN (3)
SATELLITE DRAG MODEL, NIGHT ACTIVE SUN (3)
SATELLITE DRAG MODEL, DAY QUIET SUN (1)
SATELLITE DRAG MODEL, NIGHT QUIET SUN (1)
JACCHIA
ARDC MODEL 1959
Proposal prepared by Task Group IV
October 15, 1961
ATMOSPHERIC MASS DENSITY (Kg/m³)
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
ALTITUDE (Km)
80
100
120
140
160
180
200
220
240
260
280
300

Figure A-3.

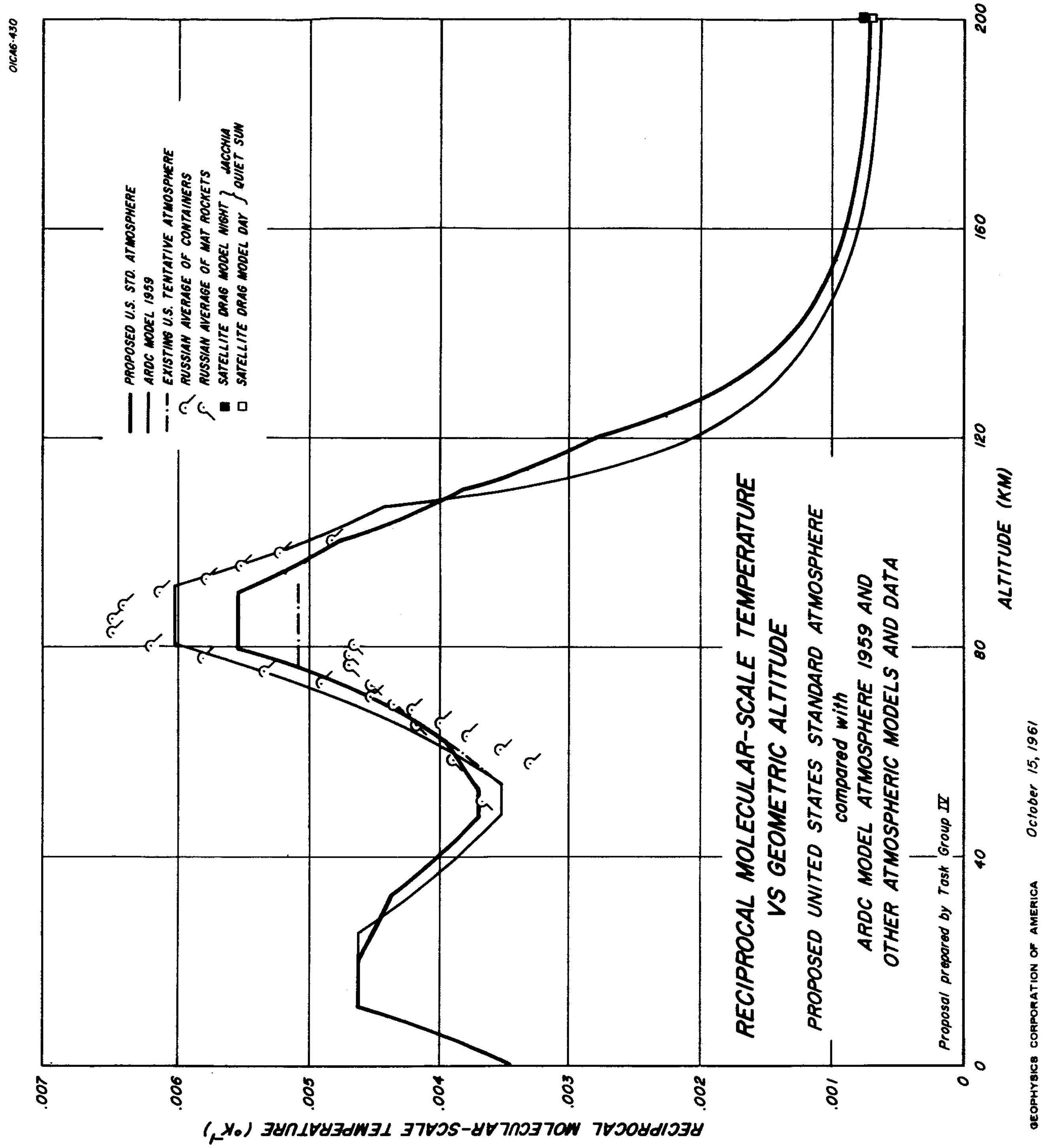

01CA6-430
RECIPROCAL MOLECULAR-SCALE TEMPERATURE
VS GEOMETRIC ALTITUDE
PROPOSED UNITED STATES STANDARD ATMOSPHERE
compared with
ARDC MODEL ATMOSPHERE 1959 AND
OTHER ATMOSPHERIC MODELS AND DATA
Proposal prepared by Task Group IV
October 15, 1961
PROPOSED U.S. STD. ATMOSPHERE
ARDC MODEL 1959
EXISTING U.S. TENTATIVE ATMOSPHERE
RUSSIAN AVERAGE OF CONTAINERS
RUSSIAN AVERAGE OF MAT ROCKETS
SATELLITE DRAG MODEL NIGHT
SATELLITE DRAG MODEL DAY
JACCHIA
QUIET SUN
ALTITUDE (KM)
RECIPROCAL MOLECULAR-SCALE TEMPERATURE (°K⁻¹)
0
40
80
120
160
200
.001
.002
.003
.004
.005
.006
.007
GEOPHYSICS CORPORATION OF AMERICA

Figure A-4.